AN EXAMINATION OF OBSERVED CLIMATIC TRENDS/CHANGES OVER BANKS PENINSULA AND THE SURROUNDING PLAINS AREA, AND THEIR SYNOPTIC CLIMATOLOGY.

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ABSTRACT

Rainfall and temperature data were collected over the study area (approximately 50 sites), using all existing climatic records, to analyse observed climatic trends/changes since instrumental records began. These trends ,using multiple regression analysis, were then compared to changes in synoptic flow patterns based on daily surface charts for the 1929 to 1985 period. Results indicate that changes in synoptic flow pattern have a very significant impact on rainfall and temperature trends.

Observed rainfall trends tend to show cyclic trends or spells of wet and dry periods. Comparison with the literature suggests that some of the observed 10 year rainfall trends were related to the sunspot cycle, such as the winter rainfall trend. However changes in synoptic flow patterns appear to be the most important factor influencing rainfall trends. Temperature trends show a much stronger relationship with synoptic flow patterns than rainfall, particularly for maximum temperature trends.

Wet periods over the study area are categorised by increased

cyclonic activity in combination with increased southerlies and or, easterly circulations while dry periods are related to anticyclonic conditions and increased westerly circulation. Southerly, and to a lesser exent easterly circulations, have the most significant influence on temperature trends with a negative impact.

The synoptic climatology of daily rainfall patterns over the study area indicated that the dominant rain-bearing winds come from the southerly quarter, especially southwesterly airflows. Higher rainfall probability and significant daily rainfall totals occur under cyclonic conditions in association with southerly to northeasterly airflows while anticyclonic west to northerly airflows produce the lower values.

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CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION AND THESIS AIMS

Climatic fluctuations and variability have had an important impact on man's activities. They have also influenced the development and progress of mankind on a global scale. Concern has recently been shown about the deterioration of the world's climate because of its impact it could have on the world economy and subsequent effects. Many disasters have been attributed to changes in climatic conditions such as the severe frequently experienced in the Northern Hemisphere and the droughts of the Sahel region. Widespread concern has developed over the last 20 years of the possible impact of man's activities in changing the climate such as due to increased output of carbon dioxide and waste heat. Research has recently been undertaken to advise various organisations and governments on possible future climatic conditions such as estimates of temperature fluctuations and trends over the next 30 to 50 years.

Climatology deals with the atmospheric conditions over a long time period. Climatology is concerned with the various conditions of the atmosphere that occur and everything that influences the condition of the atmosphere from locally to great regions of the earth. It is often defined inadequately as the "average weather". However, a study of climatology also deals with the extremes and variations from this average. Any study should consider the following:

1) Means,

2) extremes,

3) fluctuations,

4) trends,

5) probabilities,

6) and the variation in time and space.

Climatology is an applied science which lies between meteorology and geography, using meteorological methods while the aims and results are geographical.

The objectives of this present study are:

1) To describe climatic trends/changes in the study since instrumental records began.

2) To evaluate the influence of synoptic patterns on any observed climatic trends/changes. For example have the observed

climatic trends/changes been the result of changes in synoptic flow patterns ? The emphasis were on longer term fluctuations.

3) To relate local or regional climates to atmospheric circulation on a shorter time scale using daily data.

The remainder of this chapter is divided into three parts giving beckground to the above aims.

1.2 CLIMATIC TRENDS/CHANGES

Various time scales have been used by researchers to detect climatic trends or changes over time using various techniques. The most commonly used time scale in these studies ranged from 5 to 30 years (Salinger 1979, Trenberth 1977, Hessell 1980). Climatic changes is concerned with fluctuation and variation of the state of the atmosphere from the "average" climatic values. When abnormal climatic conditions become "normal" climatic conditions at particular locations, a climatic change can be said to have occurred. They appear, for example, as changes of the level of temperature in different parts of the world.

A climatic trend is the direction the climate is or has been heading, that is, a warming or cooling trend over time. However the enormous year to year variability of climate may hide any apparent trends. Various statistical techniques have been used to remove these short term irregularities. The simplest technique is the rumming mean (average) which involves calculating mean values for successive , overlapping periods of five of more years as shown below:

Year 1 + Year 2 + year 3 + year 4 + year 5 / 5 = mean1

Year 2 + Year 3 + year 4 + year 5 + year 6 / 5 = mean 2 etc.

This simple technique smooths out the short term fluctuations, particularly if periods of 20 years or more are used. These methods have been used to detect periods of warm and cool temperatures since instrumental records began, for example, the warm spell experienced in the Northern Hempishere from 1900 to 1950.

These studies have assumed greater importance as climatic changes have been seen to have important economic implications on a global scale in areas such as agriculture production, transportation systems, and resource management and planning.

1.3 INFLUENCE OF SYNOPTIC PATTERNS

Great variations of climate have occurred over the globe in the 20th Century. These variations heve been related to fluctuation in atmospheric circulation (Trenberth 1976). Changes in atmospheric circulation are likely to lead to changes in climatic conditions experienced at a particular location. The recent climatic fluctuations have been related to the strength of the global wind circulation. The warm period of the first half of the 20th Century was related to increased vigour of the westerlies over the North Altantic, northeast trades, summer monsoon of Southern Asia, and Southern Hemisphere westerlies (Barry and Chorley 1975). The key to these atmospheric variations has been linked to the heat balance of the earth - atmospheric system but this is beyond the scope of this thesis. This thesis is solely concerned with examining the relationship between changes in synoptic circulation and rainfall and temperature trends on a local scale. The complex topography of Banks Peninsula is likely to have an effect here.

1.4 SYNOPTIC CLIMATOLOGY

Synoptic climatology is concern with looking at local or regional climates by examining the relationship of weather elements to atmospheric circulation. There are two stages to a synoptic climatology studies:

1) The determination of categories of atmospheric circulation type.

2) The assessment of weather elements in relation to these

categories.

Various synoptic climatological studies have been conducted relating meteorological data to synoptic circulation. Barry and Perry (1973) provides an extensive cover of the various techniques used in synoptic climatology, and gives various examples of research that have been conducted in this field as well as practical applications of the synoptic climatological approach. According to Barry and Perry (1973) all synoptic climatological studies have one basic aim:

" To interpret spatial and temporal climatic patterns in terms of large scale weather processes and events."

This thesis is concerned with relating the rainfall patterns and distribution over the study area under different synoptic airflows.

1.5 THESIS FORMAT

The stucture of the present study is as follows:

Chapter 2 provides a background to the nature and location of the study area, and the climate of the Canterbury region. A description is made of data collection, sources and what they were required for. The methology of pre-processing the climatic records is presented in Chapter 3. Chapter 4 provides the detailed background climatology of Banks Peninsula in terms of rainfall and temperature. Comparisons are made between Banks Peninsula and surrounding plain's area. Chapter 5 discusses the observed climatic trends shown in the rainfall and temperature records at various sites over the study area. Ten and thirty year moving trends are used. The influence of trends in synoptic circulation on rainfall and temperature is assessed in Chapter 6 using multiple regression analysis. The synoptic climatology of the study area is examined in Chapter 7 for determining rainfall probabilities and average daily rainfall totals under different synoptic flow patterns. Chapter 8 summarises the results and presents directions for further research.

CHAPTER TWO

STUDY AREA, DATA COLLECTION, AND CANTERBURY CLIMATE

2.1 INTRODUCTION

This chapter is divided into three main sections. The first section describes the location of the study area with a general description of Banks Peninsula topography and comparison with the Canterbury Plains. The second section discusses the climatic controls on New Zealand's weather, particularly the South Island. A general description is given of Canterbury's climate,concentrating on the Banks Peninsula area. The third section deals with the types of data that were collected and how they were obtained. The history of some of the stations used in the study is given in terms of where they are located, who operated them, their record length, and any known site changes.

2.2 LOCATION OF STUDY AREA

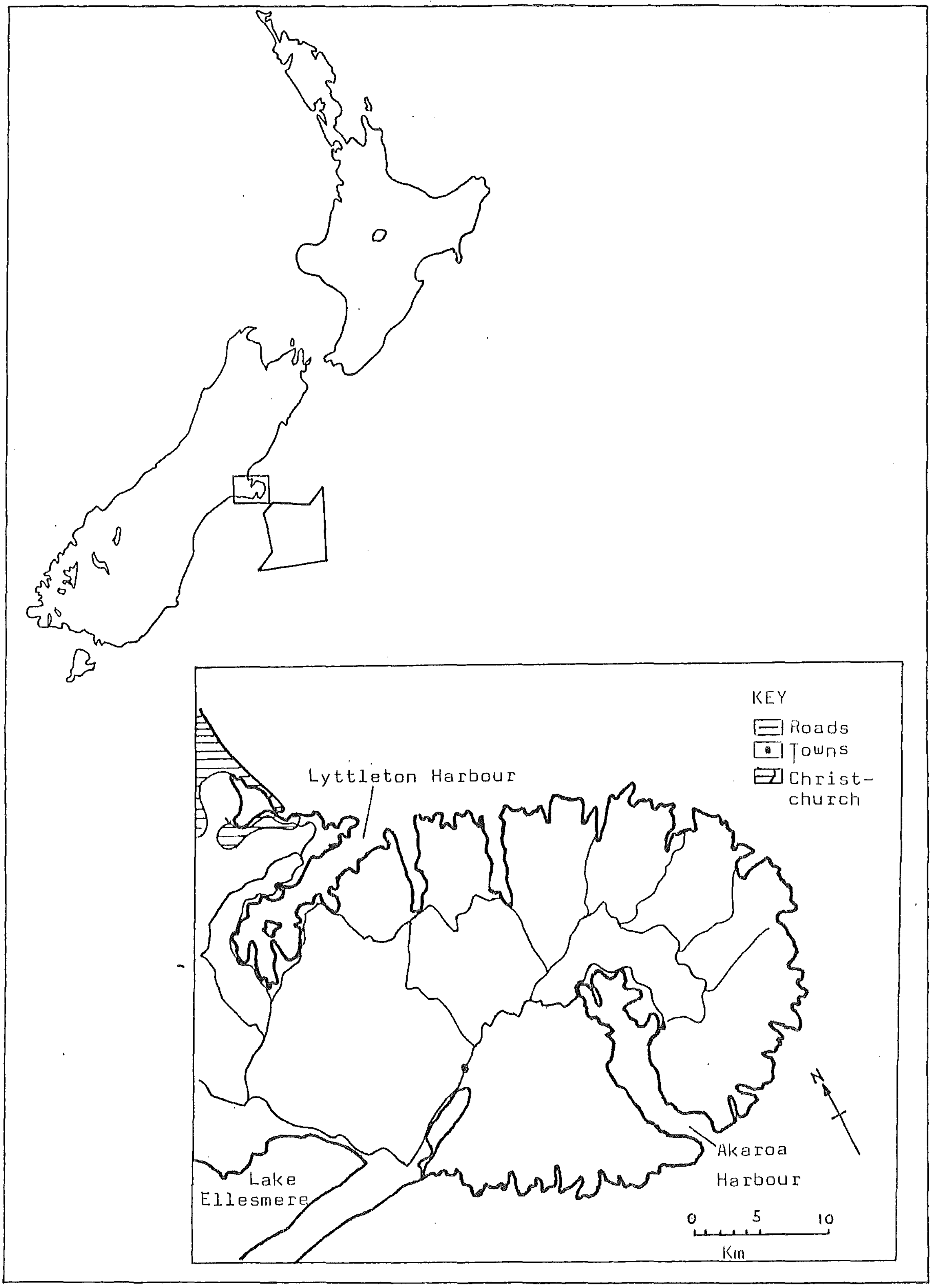
New Zealand lies in the Southwest Pacific region between latitudes 34 º S and 47º S, and between longitudes 171º E and 179 º E. It has three main islands; the North Island, South Island, and Stewart Island. Banks Peninsula is located on the eastern side of the South Island at approximately 43º32' S, and 172º40' E.

Banks Peninsula is situated on the northeast edge of the low lying Canterbury Plains. To the north of Banks Peninsula is the city of Christchurch (43º30'S,172º40'E) which has a population of approximately 300,000. To the southwest is Lake Ellesmere (Figure 2.1).

The Canterbury Plains are flat and low lying. They are approximately 40 to 60 km in width rising gently from sea level at the coast to approximately 350m above sea level at the foothills of the Southern Alps. The Canterbury Plains are approximately 200km long with 150km south of Christchurch and 50km north.

In contrast to the Canterbury Plains, Banks Peninsula is a steep, rugged, and, dissected hill country with many valleys. It is made up of two, and possibly three, extinct volcanoes. Akaroa and

FIGURE 2.1 LOCATION OF BANKS PEINISULA



Lyttelton Harbours are the main harbours being the remains of two of the volcanoes (Sparrow et al 1977). The former crater rims now range from 450m to 907m above sea level. The valleys which run from these peaks are very steep sided and most are narrow bottomed. Near the tops where the soils are thinner many rock outcrops occur (Sparrow et al 1977).

Banks Peninsula has many bays on its periphery. The bays on the northern and northeastern side are more accessible than the others, and have therefore been more attractive to settlement and recreation. Many of the headland areas have been eroded by the sea forming sheer cliffs (Sparrow et al 1977).

2.3 CLIMATE

The New Zealand climate ranges from subtropical in the north to cool temperate maritime climate in the south. Mountain climates also occur in New Zealand and some of the inland areas of New Zealand experience semi-continental climates. New Zealand lies in the westerly wind belt, a zone of interaction between subtropical and polar air masses. A procession of anticyclones, dominates the climate, crossing New Zealand every seven to ten days.These anticyclones dominantly move in an eastward direction. Separating the anticyclones are troughs of low pressure usually containing a cold front. The sequence is sometimes disrupted by blocking anticyclones, secondary development of frontal troughs, and decaying tropical cyclones from the north (Sturman 1986).

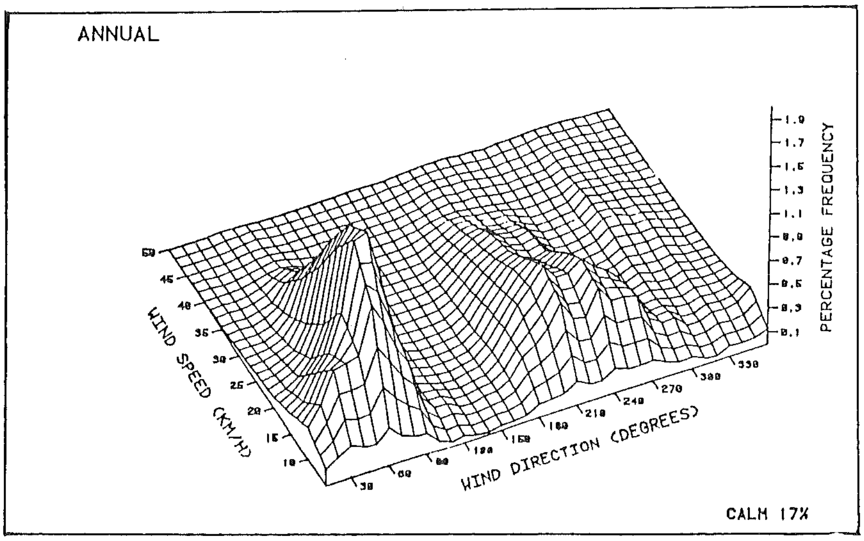
The Southern Alps act as a barrier to westerly airstreams flowing over New Zealand. This barrier has a significant effect on the climate. On the windward side (West Coast) the rainfall is enhanced by topographic forcing of westerly airstreams causing orographic rainfall. On the leeward side, the Canterbury Plains and to some extent Banks Peninsula, is a rain shadow area where low rainfall totals occur (Mc'Gann 1983).

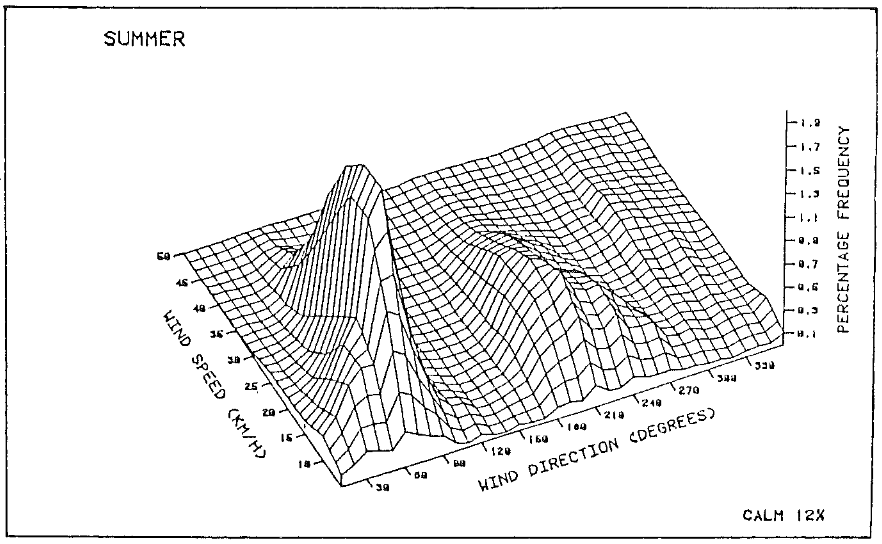
The mountain barrier also affects the wind climate of the Canterbury Plains, especially the coastal areas. The Southern Alps provide a barrier to mid-latitude westerlies leading to a high frequency of winds from the northeast and southwest in Canterbury (Mc kendry 1983). Lee troughs usually develop over the Canterbury Plains in northwesterly airstreams so that low level winds funnelling through the Cook Strait recurve back onto the Canterbury coast north of Banks Peninsula as a cool moist northeasterly wind. The coastal areas of the Canterbury Plains frequently experience northeasterly winds when northwesterly airstreams flow over the South Island (Mc Kendry 1985). Local thermo-topographic wind systems, such as the sea breeze, also allow the notheast wind to dominate the wind climate. The sea breeze is most dominant in terms of speed and frequency in spring and summer, and less dominant in winter. Southwest winds are dominant in winter when southwest gradient airflows move more frequently across New Zealand (Mc Gann 1983). Figure 2.2 shows the percentage frequency of occurrence of winds at sea breeze, also allow the notheast wind to dominate the wind climate. The sea breeze is most dominant in terms of speed and frequency in spring and summer, and less dominant in winter. Southwest winds are dominant in winter when southwest gradient airflows move more frequently across New Zealand (Mc Gann 1983). Figure 2.2 shows the percentage frequency of occurrence of winds at Christchurch Airport.

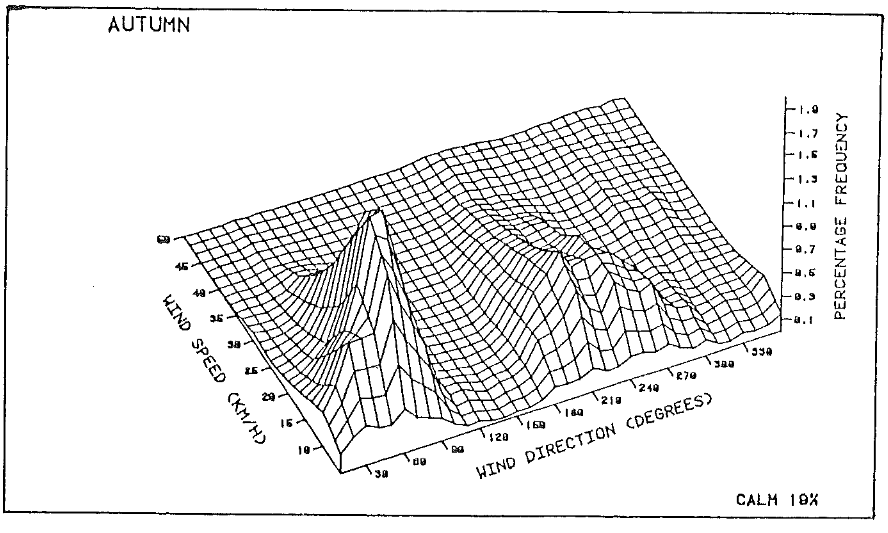
Approximately 75 percent of rainfall occurs with winds between south and west on the plains surrounding Banks Peninsula. Southwest winds contribute to about 50 percent of the rainfall that falls (Mc Gann 1983). This rainfall can be heavy when southerlies are associated with a depression lying between Banks Peninsula and the Chatham Islands. Occasionally strong moist easterly airstreams bring heavy rainfall. Due to topographic forcing, rainfall on Banks Peninsula tends to be higher under these two situations.

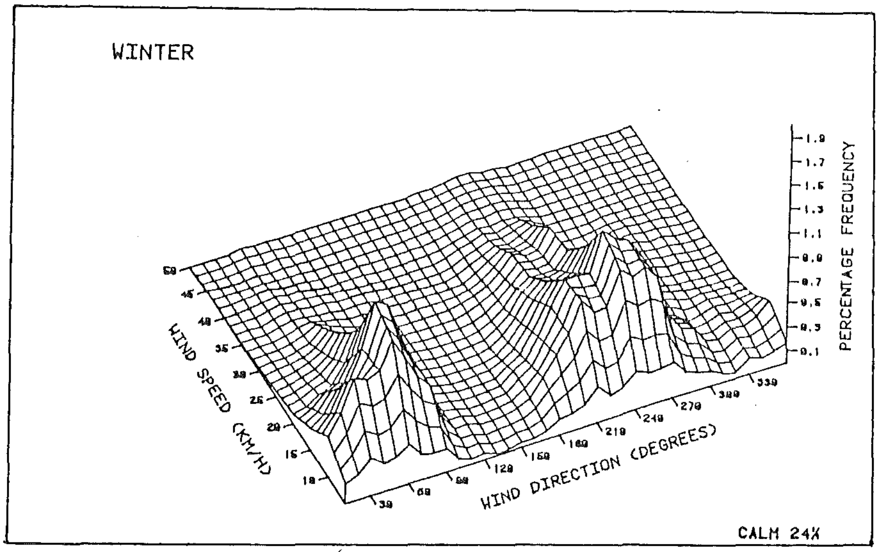
Only a generalised picture of Banks Peninsula climate is known at present, which differs from that of the Canterbury Plains. In terms of temperature, it is warmer than coastal Canterbury at similar

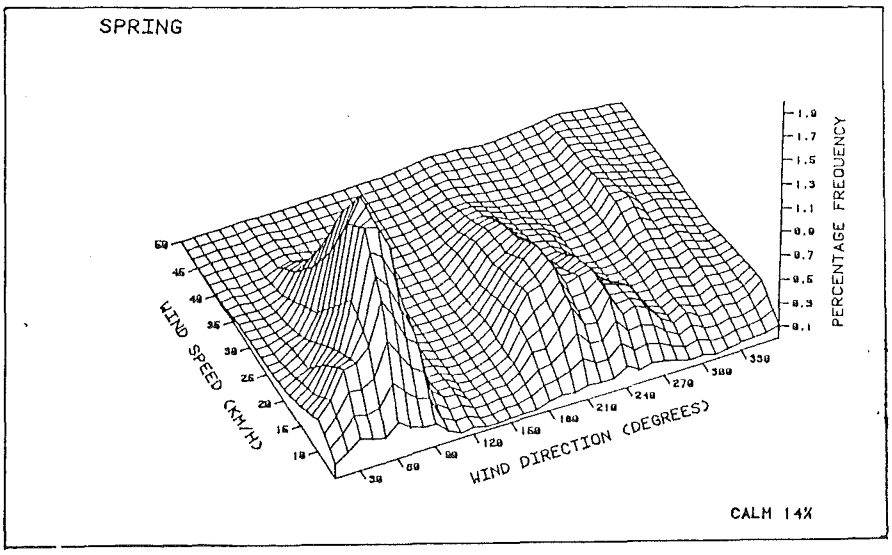
FIGURE 2.2 PERCENTAGE FREQUENCY OF ANNUAL AND SEASONAL WINDS AT CHRISTCHURCH AIRPORT











SOURCE: M^{c}GANN (1983)

altitudes. In Akaroa harbour the average annual temperature is 12.4ºC compared to Christchurch's 11.6ºC and Lincoln's 11ºC. More extreme maximum and minimum temperatures occur on the plains than on Banks Peninsula (Table 2.1). Most of Banks Peninsula receives more than 750mm of rainfall per year while the Canterbury Plains has generally less than 750mm of rainfall per year. This is because Banks Peninsula is more exposed to the rain-bearing winds from the northeast to the southwest. This is especally so in are exposed to the south and east in higher altitude regions (Sturman 1986). The peninsula has a distinctive rainfall maximum from May to August probably due to the more frequent occurence of rain-bearing southwest winds (Table 2.2). Snow usually falls in the higher altitude regions of Banks Peninsula during winter but clears quickly.

DATA COLLECTION

2.4.1 SOURCES

Most of the data collected came from stations that are part of the Meteorological Service's network which is dominantly operated by local farmers.

Rainfall data

Most of the daily rainfall data were obtained from the Meteorological Service at Christchurch Airport for the 1982-1985

TABLE 2.1: COMPARISON OF ONAWI'S TEMPERATURES TO THE SURROUNDING PLAIN'S TEMPERATURE.

TEMPERATURES (ºC)

	ANNUAL AVERAGE			EXTREMES		MEANS		FROST (Days)		
	Max	Min	Mean	Max	Min	Jan	Jul	Ground	Air	Lowest ground temp
ONAWE	16.7	8.1	12.4	35.6	-2.6	17.1	7.2	63.7	3.3	-9.3
CHRISTCHURCH	16.5	6.8	11.6	41.6	-7.1	16.6	5.9	88.7	35.7	-14.9
CH-CH AIRPORT	16.6	6.5	11.6	40.0	-7.2	16.9	5.7	84.2	44.9	-10.1
LINCOLN	16.2	5.8	11.0	40.4	-11.6	16.0	5.4	89.7	39.1	-14.4

TABLE 2.2: COMPARING RAINFALL PATTERNS OF BANKS PENINSULA AREA TO THE SURROUNDING PLAINS AREA

	J	F	M	A	M	J	J	A	S	O	N	D	TOT
PLAINS													
CHRISTCHURCH	54	43	52	55	70	64	70	55	46	44	48	56	658
AIRPORT	49	39	59	56	64	52	66	53	41	43	48	51	625
LINCOLN	55	46	57	54	64	62	68	55	47	46	52	57	662
BANKS PENINSULA													
AKAROA	71	63	77	84	112	121	143	118	84	74	68	74	1092
ALLANDALE	65	55	61	70	103	93	106	88	60	63	61	68	896
OKUTI	84	65	80	93	148	135	148	137	88	81	73	81	1213
LITTLE AKALOA	54	45	55	72	99	91	94	83	57	52	50	61	812

period, while data for the 1978-1981 period also originated with the Meteorological Service. Monthly and annual rainfall totals were similarly derived from the Meteorological Service.

Hugh Wilson and Russell Sanders also gave information regarding local rain gauge operators in the Banks Peninsula area.

Temperature data

Most of these data were obtained from the Meteorological Service. Only nine stations have recorded temperature data and most are located on the plains in the Christchurch area. Only Onawi has recorded temperature data for any reasonable length of time in the Banks Peninsula area (1937-1972). Akaroa (1978-1986), Quail Island (1983-1986), and Catons Bay (1983-1986) have short records.

Monthly and annual mean, maximum, and minimum temperature data were obtained from published New Zealand Meteorological Service climatological tables and at Christchurch Airport.

Weather charts

Daily weather charts were obtained from three sources to determine the synoptic flow patterns over the South Island:

1) Pre 1961 weather charts from the Meteorological Service Headquarters at Wellington.

2) The 1961 to 1980 daily categorization tables of synoptic flows over the South Island from Sturman et al (1984).

3) The 1981-1985 weather charts from Christchurch Airport.

2.4.2 REQUIREMENTS

The following is a list of the data used :

1)Monthly, seasonal, and annual rainfall were used for temporal and spatial mapping of the study area's rainfall pattern. The data were also used for 10 and 30 year moving trends. Moving trends were used to detect any climatic trends/changes that occurred over the observed period.

2) Monthly, seasonal, and annual temperature data. Mean, maximum, and minimum temperatures were given the same analysis as the above rainfall data.

3) Daily weather charts. These were required for two main reasons:

a)To determine if synoptic flow patterns were influencing any observed climatic trends/changes since 1929.

b)To determine the influence of synoptic flow patterns on daily rainfall and temperature patterns in the study area. The 1981-1985 period was chosen as the period to carry out this analysis.

4)Daily rainfall (1981-1985). These data was required for the synoptic rainfall climatology aspect of the study as discussed above.

2.5 HISTORY OF STATIONS

Approximately 40 to 50 stations were used in the study area.Most of these stations are part of the New Zealand Meteorological Service observation network.

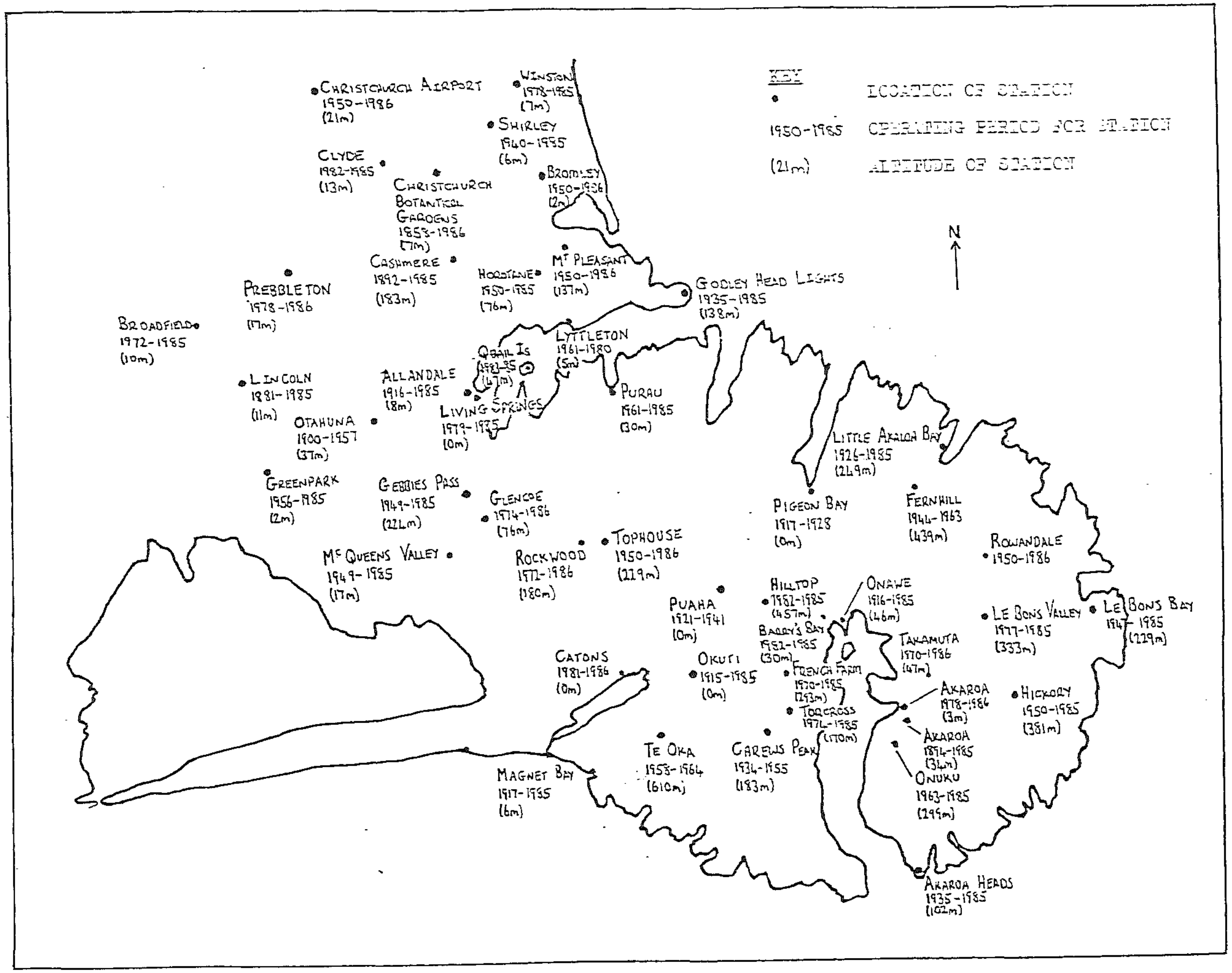
Most stations are relatively low in altitude being below 250m above sea level. Most stations are located within four major areas:

1) Around Christchurch City area.
2) Lyttelton Harbour.
3) Akaroa Harbour.
4) Easily accessible bays and valleys of Banks Peninsula.

These four major regions are where the main settlements occur in the study area, and which tend to be low in altitude and or, in valley bottoms, and located close to the main transport routes. Approximately over half of the stations are still operating today but many stations have operated for less than 50 years. Farmers are the main people who operate the stations in the Banks Peninsula area, hence most stations only record rainfall data. Stations with records longer than 50 years are located in the major settlement areas. Only Christchurch Botantical Gardens, Lincoln, Cashmere, and Akaroa have records that go back into the 19th century.

Figure 2.3 shows the locations of the stations in the study area, their operating period, and altitude.

FIGURE 2.3 LOCATION OF RAINFALL AND CLIMATOLOGICAL STATIONS IN THE STUDY AREA



CHAPTER THREE

PRE-PROCESSING OF THE CLIMATIC RECORD

3.1 INTRODUCTION

Assessing the reliability of climatic records is a major component of this study, as discussed in chapter two. If the data are unreliable, the results also become unreliable. The data must be checked for reliability using homogeneity analysis.

Before homogeneity analysis could be used a set of criteria had to be established to group stations with similar climatic records. The first section of this chapter discusses the criteria used and the reasons why they were chosen.

Homogeneity technique were used to correct unreliable data in the climatic records. Rainfall and temperature data required slightly different homogeneity techniques and these are discussed in the second section of this chapter. A BMDP package using the "*Missing Value* " program was used to estimate suspected incorrect or missing data.

The third section shows the results of the homogeneity assessment which includes tables to illustrate the results.

3.2 GROUPING THE STATIONS INTO REGIONS FOR INTER-COMPARISON

A set of criteria had to be established to determine which stations would be grouped together for homogeneity assessment. Five criteria were used to determine the regionality and grouping of these stations.

3.2.1. TOPOGRAPHY

Relief features such as hilltops, ridges, flatness of terrain, and slope aspect were used to determine which stations would be grouped together into one region for homogeneity assessment. For example, the plains region was mainly determined by the flatness of its topography. Included in this region were stations in valleys which slope onto the Canterbury Plains.

3.2.2 PROXIMITY OF STATIONS TO EACH OTHER

The closer the stations are to each other the more likely their rainfall and temperature patterns will be similar to each other. The stations in the Christchurch region were grouped together because of their close proximity to each other. Close proximity makes it easier to detect erroneous data when homogeneity analysis is used because of the stations similar climatic record.

3.2.3 EXPOSURE TO WIND

Exposure to rain-bearing winds was an important factor as this determines how much rainfall a station is likely to receive. Stations exposed to southerly winds are more likely to receive greater rainfall totals in southerly airflows than in easterly or northeasterly airflows. This was a major factor in determining the regionality of stations in the Banks Peninsula area where ridge lines and summits were used as boundaries to separate the different regions.

3.2.4 DRAINAGE SYSTEMS

This factor was combined with ridge lines and summits, and exposure to rain-bearing winds. Akaroa and Lyttelton Harbour regions are examples of this drainage system method. Both of these harbours form natural drainage systems in to which all streams in these regions flow. Summits and ridge lines were used to determine the boundaries of these two regions. Because of the large area of these two harbours, relative to the other bays, stations in these two regions would be particularly exposed to rain-bearing winds coming through the harbour entrance. Stations in Akaroa Harbour would be exposed to rainbearing southerly winds while Lyttelton Harbour stations would be exposed to rain-bearing east to northeasterly winds.

3.2.5 THE RURAL-URBAN ASPECT OF THE STATION

Urban areas are likely to modify their climate significantly when compared to rural sites.The urban "*heat island* " is likely to affect temperature readings and to a lesser extent rainfall patterns. For this reason stations in metropolitan Christchurch were placed in a separate group from the rest of the stations on, or close to, the Canterbury Plains.

The application of these criteria to determining the regionality and grouping of stations for homogeneity assessment was subjective. An alternative method would be to use an objective approach such as using a custer analysis technique. Time contrast and unfamilarity with this technique were the reasons this method was not used.

3.3 DATA ANALYSIS

3.3.1 RATIONALE

In any climatic reseach the reliability of data is a major concern. This is particularly so when studying climatic trends, changes, and fluctuations. If the data are unreliable with incorrect values and or have missing data, the climatic trends shown are also unreliable. The trends shown may not be the result of climatic effects. Other major concerns which can cause unreliability of meteorological data include changes of recording instruments and site. Although data from most sites were reliable, there were some missing and suspected incorrect values. Luckily only Christchurch and Lincoln have had several site changes. Analysis showed that only Lincoln's temperature was significantly affected by the 1944 site change. However, a major concern of this study was with station homogeneity assessment.

3.3.1 HOMOGENEITY ASSESSMENT

Once all the available rainfall and temperature data were collected and the position of the sites plotted, stations were grouped for inter-comparison using the criteria mentioned above (Figure 3.1).

The homogeneity assessment followed the lines used by Jones et al (1985) using a program obtain from D. Norton. Table 3.1 shows an example of output from this program. For each station, the entire record is listed as anomalies from the appropriate monthly and annual mean of the entire station record. Station homogeneity assessment

FIGURE 3.1 GROUPING OF STATIONS INTO EIGHT REGIONS

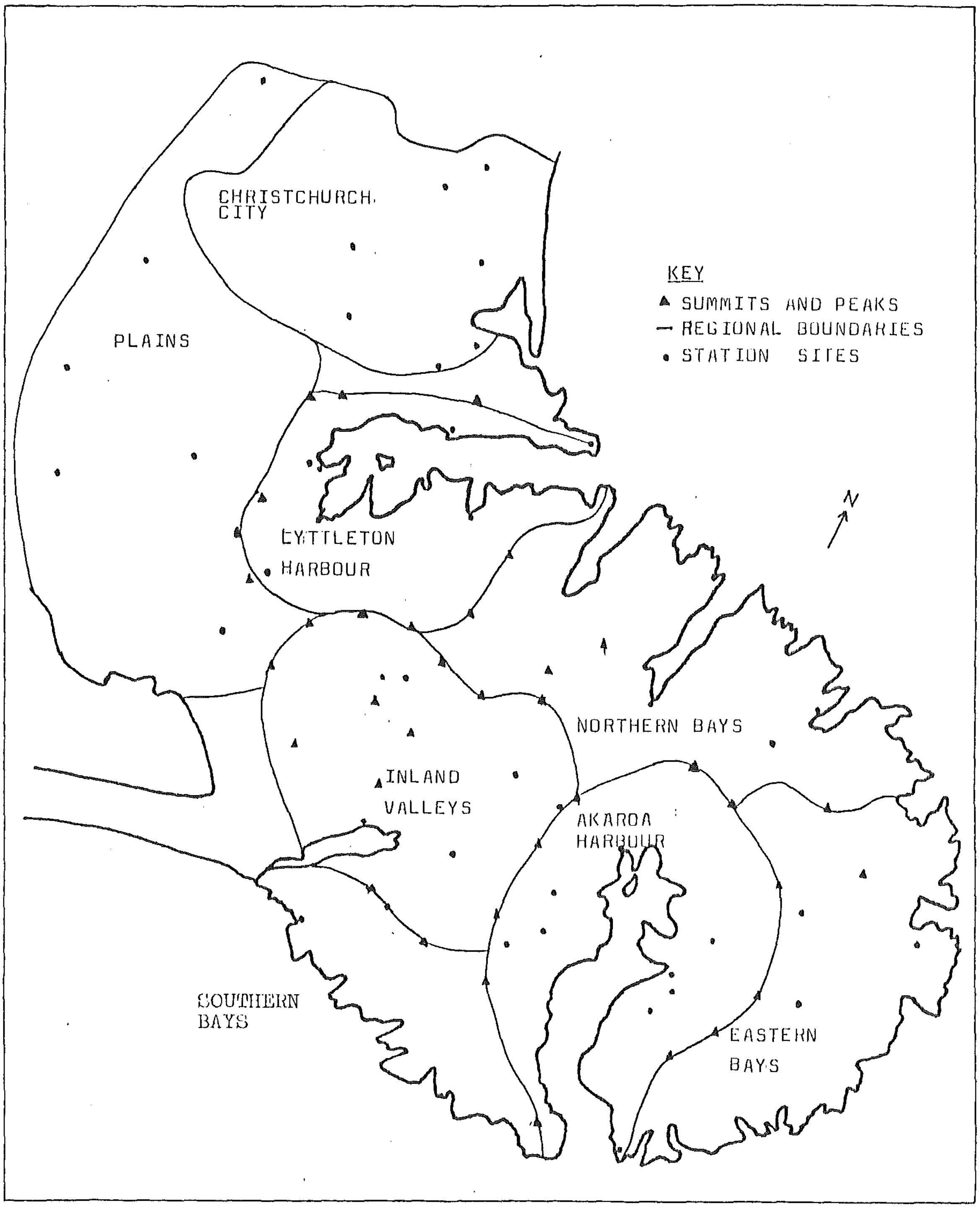


TABLE 3.1: COMPUTER PRINT OUT OF D.NORTON'S HOMOGENEITY PROGRAM

H32872 TE OKA 4349 17247 610 1958 1964

ORIGINAL DATA AND BASIC STATISTICS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1958	120	165	50	77	176	66	20	51	17	34	37	81	894
1959	40	67	154	92	247	22	83	28	13	43	41	58	888
1960	62	61	139	28	53	207	67	52	99	81	50	131	1030
1961	142	88	64	71	117	58	208	142	93	13	49	21	1066
1962	54	86	165	106	100	54	81	20	79	105	105	91	1048
1963	50	140	36	155	98	51	229	89	75	32	74	82	1181
1964	31	17	77	26	82	61	74	69	45	22	104	69	677
OBS	7	7	7	7	7	7	7	7	7	7	7	7	7
MEAN	71	89	98	79	125	82	115	73	52	43	66	76	969
S.D.	43	50	53	45	66	61	100	37	43	27	29	33	166
MIN	31	17	36	26	53	22	20	28	65	13	37	21	677
MAX	142	165	165	155	247	207	299	142	76	81	105	131	1181

Table 3.1 continue

DIFFERENCE VALUES (MEAN-OBSERVED)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1958	49	76	-48	-2	51	-16	-95	-22	-35	-9	-29	5	-75
1959	-31	-22	56	13	122	-60	-32	-45	-39	0	-25	-18	-81
1960	-9	-28	4	-51	-72	125	-48	-21	47	38	-16	55	61
1961	71	-1	-34	-8	-8	-24	93	69	41	-30	-17	-55	97
1962	-17	-3	67	27	-25	25	-61	8	-32	36	39	15	79
1963	-21	51	-62	76	-27	-31	184	16	23	-11	8	6	212
1964	-40	-72	-21	-53	-43	-21	-41	-4	-7	-21	38	-7	-292
1964	-40	-72	-21	-53	-43	-21	-41	-4	-7	-21	38	-7	-292

MONTHS WITH RAINFALL TOTALS OF MORE OR LESS THAN 1 S.D. FROM THE NEAN MONTHLY RAINFALL

1958	1	2				
1959	3	5	8	9		
1960	4	5	6	9	10	12
1961	1	8	9	10	12	
1962	3	10	11			
1963	2	3	4	7		
1964	2	4	11			

TABLE 3.2: HOMOGENEITY ASSESSMENT OF RAINFALL VALUES

ANNUAL DIFFERENCE VALUES			RATIO	di	[di-di+1]	di^2	$[di-di+1]^2$
	(S1)	(S2)	(S1/S2)				
YEAR	AKAROA	ONUKU					
1962	1092	1280	0.85	0.04	0.01	0.0016	0.0001
1963	1522	1807	0.84	0.03	0.49	0.0009	0.2401
1964	1118	840	1.33	0.52	0.46	0.2704	0.2116
1965	1230	1406	0.87	0.06	0.02	0.0036	0.0004
1966	870	1023	0.85	0.04	0.03	0.0016	0.0009
1967	823	1114	0.74	-0.07	0.12	0.0049	0.0144
1968	1196	1389	0.86	0.05	0.11	0.0025	0.0121
1969	489	649	0.75	-0.06	0.04	0.0036	0.0016
1970	951	1147	0.83	0.02	0.11	0.0004	0.0121
1971	656	905	0.72	-0.09	0.04	0.0081	0.0016
1972	812	1056	0.77	-0.05	0.06	0.0025	0.0036
1973	858	1041	0.82	0.01	0.08	0.0001	0.0064
1974	1250	1746	0.72	-0.09	0.09	0.0081	0.0081
1975	1416	1742	0.81	0.00	0.04	0.0000	0.0016
1976	1040	1346	0.77	-0.04	0.12	0.0016	0.0144
1977	1282	1437	0.89	0.08	0.02	0.0054	0.0004
1978	1537	2162	0.71	-0.10	0.01	0.0100	0.0001
1979	943	1314	0.72	-0.09	0.01	0.0081	0.0001
1980	1022	1447	0.71	-0.10	0.02	0.0100	0.0004
1981	950	1379	0.69	-0.12	0.19	0.0144	0.0361
1982	757	865	0.88	0.07	0.07	0.0049	0.0049
1983	1103	1356	0.81	0.00	0.02	0.0000	0.0004
1984	775	979	0.79	-0.02	0.00	0.0004	0.0000
MEAN	1030	1280	0.81			A = 0.3641	B = 0.5577

NUMBER OF SAMPLES = N N = 23

DETERMINING RELATIVE HOMOGENEITY OF THE TWO STATIONS

Determining limits : 1/SQR(N) = 0.209

Upper limit = 1 + 0.209 = 1.209

Lower limit = 1 - 0.209 = 0.791

Relative homogeneity : $0.791 \leq 2A/B \leq 1.209$

2A/B = 2*0.3641/0.577 = 1.306

RESULT : TWO RECORDS NOT HOMOGENEOUS

was then possible by comparing stations within the same groups. Annual rainfall and temperature anomalies at one station were compared to the other stations by plotting the differences between series as a time series, along the lines proposed by Conrad and Pollak (1950). For assessing these differences in rainfall a ratio method is used while for temperature a difference method is used. Both of these methods are discussed in detail below. If abrupt changes occurred in the different time series, monthly anomalies were compared. When comparing all stations in the group, the erroneous data become apparent, and corrections can then be made. Table 3.2 shows an example of homogeneity assessment while Figure 3.3 shows how anomalies are picked up. For example, look at the 1964 ratio value in comparison to the other ratio values.

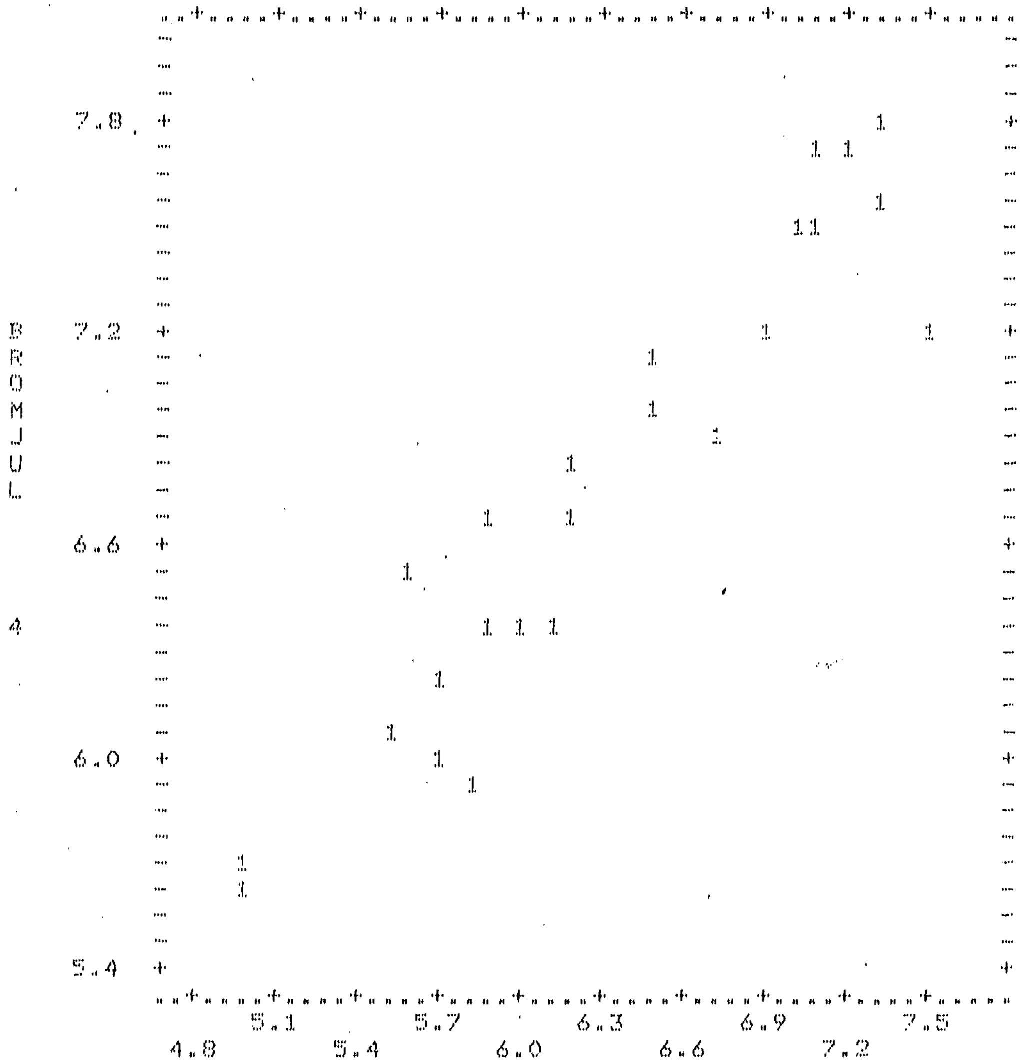
A BMDP program called "*Missing Value* " was used to obtain corrected and missing values. Correlations and linear regressions between the different stations were also obtained. The program gave estimates of missing values. These values were then compared with the other neighbouring stations. If the estimated values appeared to be incorrect after being compared to the other station's values, a linear regression equation was used to determine the value. Linear regression equations used were obtained from the "*Missing Value* " program. Table 3.3 gives an example of an ouput of the "*Missing Value*

TABLE 3.3 EXAMPLE OF ESTIMATED VALUES USING "MISSING VALUE" PROGRAM FOR MEAN JULY TEMPERATURE (ºC) FOR BROMLEY AND CHRISTCHURCH

CASE NUMBER	MISSING VARIABLE	ESTIMATE	R-SQUARED	GROUP	CHI-SQ	CHISQ/DF	D.F.	SIGNIFICANCE
4	4 BROMJUL	5.8372	0.911		2.254	0.751	3	0.5213
4	5 PLEAJUL	6.6892	0.835		2.254	0.751	3	0.5213
5	4 BROMJUL	6.0372	0.911		1.738	0.579	3	0.6285
5	5 PLEAJUL	6.9183	0.835		1.738	0.579	3	0.6285
6	4 BROMJUL	6.6691	0.911		0.161	0.054	3	0.9836
6	5 PLEAJUL	7.6021	0.835		0.161	0.054	3	0.9836
7	4 BROMJUL	6.7886	0.911		2.618	0.873	3	0.4544
7	5 PLEAJUL	7.7039	0.835		2.618	0.873	3	0.4544
8	4 BROMJUL	5.9567	0.911		5.836	1.945	3	0.1198
8	5 PLEAJUL	6.7909	0.835		5.836	1.945	3	0.1198
9	4 BROMJUL	6.5039	0.911		2.088	0.696	3	0.5543
9	5 PLEAJUL	7.3791	0.835		2.088	0.696	3	0.5543
10	4 BROMJUL	7.4225	0.911		1.465	0.488	3	0.6903
10	5 PLEAJUL	8.4771	0.835		1.465	0.488	3	0.6903
11	4 BROMJUL	6.8873	0.911		0.362	0.121	3	0.9479
11	5 PLEAJUL	7.8254	0.835		0.362	0.121	3	0.9479
12	5 PLEAJUL	8.6693	0.871		3.262	0.815	4	0.5150
13	5 PLEAJUL	7.5402	0.871		3.172	0.793	4	0.5294

Table 3.3 continue

Linear regression graph between Christchurch and Bromley for mean July temperature (°C)



N = 24
R = .9453 CHRISTJU 2
P(R) 0.000

	MEAN	ST.DEV.	REGRESSION LINE	RES.MS.
X	6.3208	.73896	X= 1.0477*Y-.77718	.06074
Y	6.7750	.66676	Y= .85293*X+ 1.3837	.04945

" program showing estimated values for missing and corrected data, as well asthe linear regression equation.

3.4 RATIO AND DIFFERENCE METHOD

The techniques used for homogeneity assessment of climatic records were discussed above. However, temperature and rainfall data used slightly different methods to determine relative homogeneity of neighbouring stations.

3.4.1 DIFFERENCE METHOD

For annual temperature, the difference method is used for homogeneity analysis. When two stations are being compared to each other their difference values are obtain by subtracting their annual temperature values. The resulting values are plotted against time. The peaks and or, troughs that occur in the plots are usually the result of erroneous values in one or more of the stations record(Figure 3.2). Abbe's Criterion was used to determine if non climatic elements influences existed in the record.

Abbe's Criterion is based on a series of deviations from an arithmetic mean d1, d2, ... , dn. From this series, two other series are arithmetic mean d1, d2, ... , dn. From this series, two other series are derived:

$$A = d1^2 + d2^2 + ... + dn^2 = \Sigma(di)^2.$$

$$B = (d1\text{-}d2)^2 + (d2\text{-}d3)^2 + ... + (di\text{-}di{+}1)^2 + ... + (dn\text{-}1 - dn)^2 + (dn\text{-}di)^2 = \Sigma(di\text{-}di{+}1)^2.$$

di is the the sum of the mean differences (di) minus the individual differences for each year. If the resultant values lie between the limits specified (1+- sqr(1/N)) as shown in Table 3.4, the series are homogeneous (Conrad and Polak 1950). Abbe's Criterion was only used on temperature data because of the small deviation in the plotted difference values; whereas in the rainfall data the plotted ratio values show obvious deviations (Figure 3.2).

Once erroneous values were discovered, monthly temperature values were checked to discover which were incorrect. The BMDP "*Missing Value* " program was then used to correct those values as shown in Table 3.3, and to estimate missing values.

3.4.2 RATIO METHOD

The ratio method was used for homogeneity analysis of annual rainfall data. Whereas the temperature annual values are subtracted, the rainfall annual values are divided to obtain the ratio values (Table 3.2). The resulting annual ratio values are plotted against time to detect any significant deviations in the record. Any troughs or crests

TABLE 3.4 : AN EXAMPLE OF HOMOGENEITY ANALYSIS OF TEMPERATURE VALUES

	BROMLEY	CH-CH*	(S1-S2)	(Di)	(Di-Di+1)	$(di)^2$	$(di-di+1)^2$
YEAR	S1	S2					
1962	12.4	12.6	-0.2	-0.4	0.4	0.16	0.16
1963	11.7	11.5	0.2	0.0		0.00	
1964		11.9					
1965	11.7	11.6	0.1	-0.1	0.1	0.01	0.01
1966	11.8	11.8	0.0	-0.2	0.0	0.04	0.00
1967	11.9	11.9	0.0	-0.2	-0.2	0.04	0.04
1968	12.1	11.9	0.2	0.0	0.0	0.00	0.00
1969	12.2	12.0	0.2	0.0	0.2	0.00	0.04
1970	12.5	12.5	0.0	-0.2	-0.1	0.04	0.01
1971	12.8	12.6	0.2	-0.1	-0.1	0.01	0.01
1972	12.1	11.9	0.2	0.0	0.0	0.00	0.00
1973	12.6	12.4	0.2	0.0	0.0	0.00	0.00
1974	12.2	12.0	0.2	0.0	-0.1	0.00	0.01
1975	12.5	12.2	0.3	0.1	-0.3	0.01	0.09
1976	11.6	11.0	0.6	0.4	0.1	0.16	0.01
1977	11.8	11.3	0.5	0.3	0.3	0.09	0.09
1978	12.8	12.6	0.2	0.0	-0.3	0.00	0.09
1979	12.5	12.0	0.5	0.3		0.09	
1980	12.3						
1981	12.7	12.5	0.2	0.0		0.00	
1982		12.0					
1983	11.9	11.8	0.1	-0.1		0.01	
1984	12.5						
MEAN	12.2	12.0	0.2		SUM	A = 0.70	B = 0.40

Table 3.4 continue

NUMBER OF SAMPLES = N   N = 23

DETERMINING RELATIVE HOMOGENEITY OF TWO CLIMATIC RECORDS

DETERMINING LIMITS : 1/SQR(N) = 0.209
UPPER LIMIT = 1 + 0.209 = 1.209
LOWER LIMIT = 1 - 0.209 = 0.791

RELATIVE HOMOGENEITY : $0.791 \leq 2A/B \leq 1.209$
2A/B = 2*0.70/0.4
= 3.5

RESULT: TWO RECORDS NOT HOMOGENEOUS

*Christchurch Botantical Gardens

FIGURE 3.2 : AN EXAMPLE OF PLOTTED DIFFERENCE VALUES FOR ANNUAL TEMPERATURES AT BROMLEY (S1) AND CHRISTCHURCH (S2)

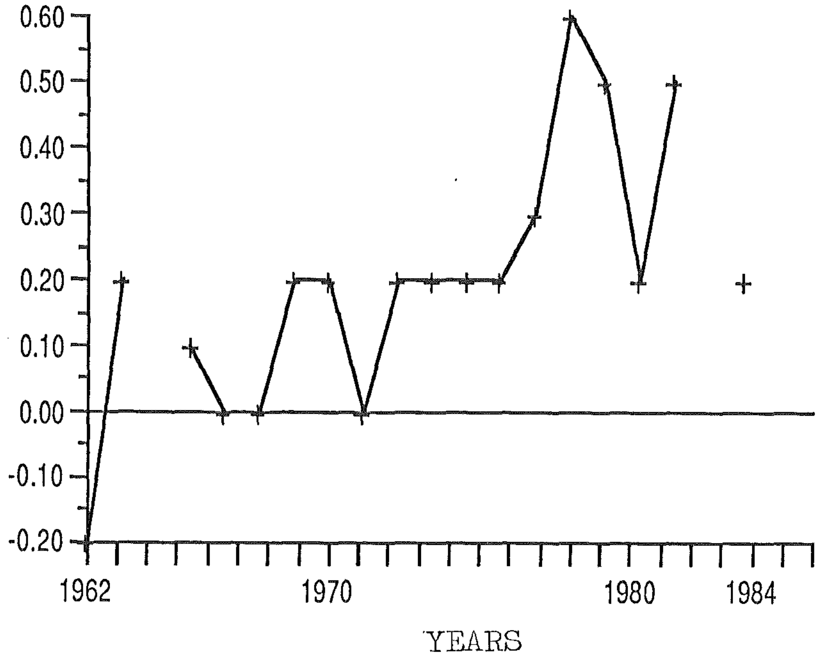
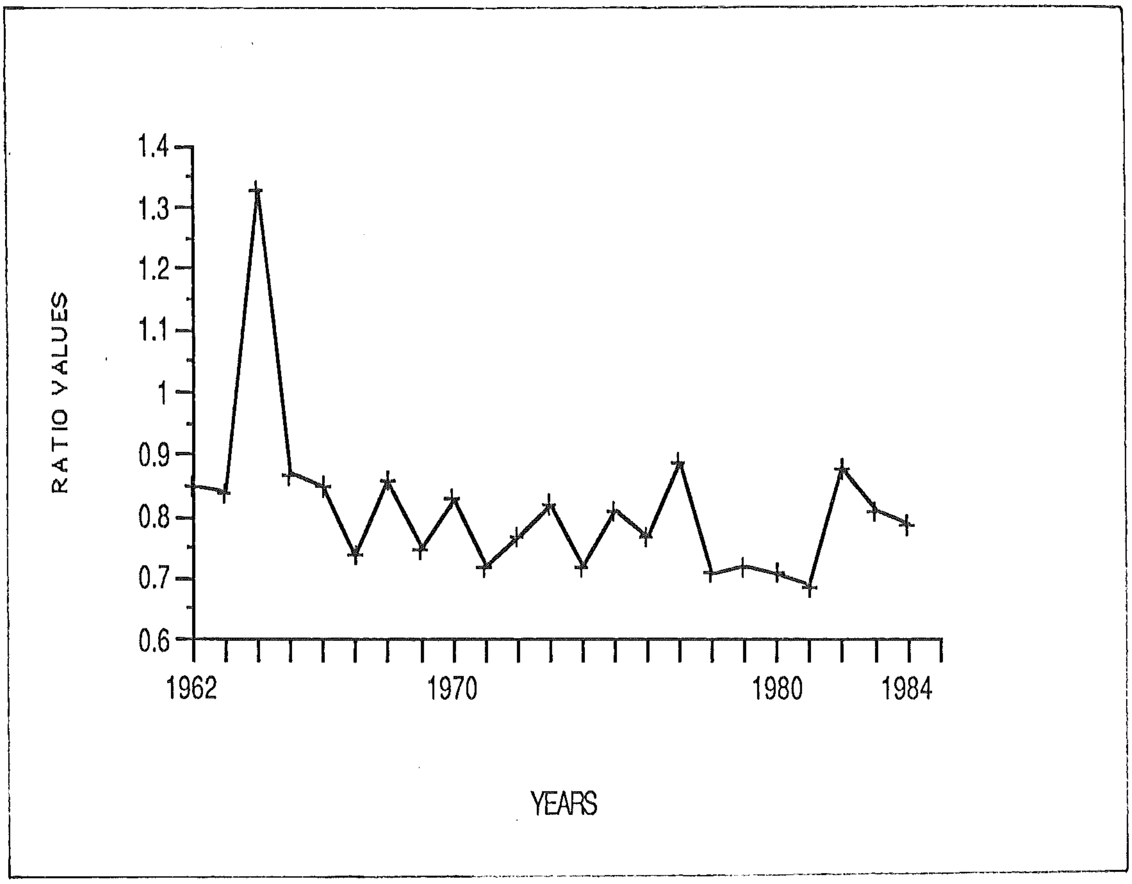


FIGURE 3.3 AN EXAMPLE OF PLOTTED RATIO VALUES FOR ANNUAL RAINFALL AT AKAROA (S1) AND ONUKU (S2)



that occur are usually the result of one or more stations having incorrect value(s) (Figure 3.3). Abbe's Criterion, as discussed in the above section, was used to determine if the series was homogeneous. If the series was not homogeneous, the station(s) with the erroneous values had their monthly values checked to discover which monthly value(s) were incorrect.

The BMDP "*Missing Value* " program was used to correct the erroneous values. Table 3.5 shows one of the stations rainfall record before and after the corrections were done.

3.5 RESULTS FROM PRE-PROCESSING THE CLIMATIC RECORD

Once the homogeneity analysis had been conducted and new values checked for suitability, the missing values and corrected values were placed in the appropriate climatic records. Then each of the stations that had new values were re-run through D.Norton's computer programme to obtain new monthly, and annual rainfall and temperature mean values and standard deviations.

The same process was conducted for the temperature. Table 3.6 shows examples of stations that had their records improved and or , extended.

However, there is a possibility that localised heavy rainfall

TABLE 3.5 AN EXAMPLE OF ORIGINAL RECORD AND THE NEW IMPROVED RECORD AFTER HOMOGENEITY ANALYSIS

Mc QUEENS VALLEY ORIGINAL RAINFALL RECORD

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1955	21	69	31	22	86	142	128	28	42	27	36	9	641
1956	51	13	57	30	172	28	102	59	102	68	98	57	837
1957	12	27	113	85	164	35	102	25	46	61	63	85	818
1958	81	105	39	101	94	66	14	34	12	35	28	51	660
1959	36	55	120	76	227	15	36	17	11	68	33	41	735
1960	43	63	93	26	23	124	46	55	48	32	43	125	721
1961	77	59	42	35	66	39	115	114	75	4	26	16	668
1962	45	64	92	101	51	93	62	58	17	40	84	65	772
1963	37	92	47	68	54	63	152	93	42	26	75	86	835
1964	16	20	71	36	53	34	63	50	32	15	58	34	482
1965	71	29	122	89	73	92	100	73	31	39	101	21	841
1966	83	46	54	57	76	37	58	67	34	31	89	45	677
1967	76	49	39	46	100	39	15	49	73	51	121	33	691
1968													
1969	96	28	18	60	76	40	56	35	26	40	14	64	553
1970	59	29	149	16	84	98	108	30	64	58	55	28	778
1971	26	17	35	20	88	104	82	39	38	24	99	17	589
1972	77	29	25	65	178	68	56	44	19	99	30	36	726
1973													
1974	37	99	89	190	73	67	92	112	57	87	11	13	927

Table 3.5 continue

1975													
1976	80	47	14	55	49	74	97	138	43	76	45	106	824
1977													
1978	56	12	46	184	56	110	143	91	113	71	41	131	1054

NEW IMPROVED RAINFALL RECORD

1948*	66	65	27	53	94	54	65	12	51	33	90	6	616
1949*	107	14	66	47	63	74	64	68	13	33	23	75	647
1950*	50	59	60	52	45	54	72	65	21	68	59	102	707
1951*	69	103	134	139	105	76	67	38	19	79	42	91	962
1952*	40	31	36	31	77	51	35	129	62	82	96	43	713
1953*	91	62	76	101	81	73	65	51	38	61	20	58	777
1954*	25	32	64	29	70	51	119	87	27	17	44	61	626
1955	21	69	31	22	86	142	128	28	42	27	36	9	641
1956	51	13	57	30	172	28	102	59	102	68	98	57	837
1957	12	27	113	85	164	35	102	25	46	61	63	85	818
1958	81	105	39	101	94	66	14	34	12	35	28	51	660
1959	36	55	120	76	227	15	36	17	11	68	33	41	735
1960	43	63	93	26	23	124	46	55	48	32	43	125	721
1961	77	59	42	35	66	39	115	114	75	4	26	16	668
1962	45	64	92	101	51	93	62	58	17	40	84	65	772
1963	37	92	47	68	54	63	152	93	42	26	75	86	835
1964	16	20	71	36	53	34	63	50	32	15	58	34	482
1965	71	29	122	89	73	92	100	73	31	39	101	21	841
1966	83	46	54	57	76	37	58	67	34	31	89	45	677
1967	76	49	39	46	100	39	15	49	73	51	121	33	691

Table 3.5 continue

1968*	73	41	38	210	59	73	86	24	30	34	70	56	794
1969	96	28	18	60	76	40	56	35	26	40	14	64	553
1970	59	29	149	16	84	98	108	30	64	58	55	28	778
1971	26	17	35	20	88	104	82	39	38	24	99	17	589
1972	77	29	25	65	178	68	56	44	19	99	30	36	726
1973*	27	25	36	20	68	50	64	119	41	28	45	43	566
1974	37	99	89	190	73	67	92	112	57	87	11	13	927
1975*	54	73	71	60	40	167	95	93	40	44	66	31	834
1976	80	47	14	55	49	74	97	138	43	76	45	106	824
1977*	63	71	11	29	118	124	154	39	91	41	33	48	822
1978	56	12	46	184	56	110	143	91	113	71	41	131	1054
1979*	20	54	120	12	125	3	117	137	26	110	55	32	811
1980*	123	61	98	77	27	69	53	60	10	24	90	28	720
1981*	23	18	46	48	47	114	118	151	23	95	39	15	737
1982*	26	22	23	48	49	61	67	30	26	89	56	91	588
1983*	29	25	33	105	99	77	94	41	94	40	25	85	747
1984*	78	61	94	20	62	31	101	20	36	41	76	45	665
1985*	8	66	46	10	51	32	59	55	30	40			

* All values in that year are estimated

TABLE 3.6 EXAMPLES OF SOME OF THE STATIONS THAT HAD THEIR RECORDS ALTERED AND , OR , EXTENDED

RAINFALL

Name of station	Date of change month(s)	Year	Type of value Corrected/ Missing	Extended
Akaroa	feb	1937	√	
	jun,jul,sep	1943	√	
	oct	1952	√	
	may,jun	1961	√	
Allandale	sep...dec	1915		√
	jan...may	1916		√
	feb...apr	1935	√	
	may	1937	√	
	may...dec	1974		√
	jan...dec	1975-1985		√
Cashmere	oct	1924	√	
	may,jul	1970	√	
	jan...dec	1976-1985		√
Christchurch	may	1923	√	
	sep	1956	√	

Table 3.6 continue

Onawe	sep	1940	√	
	jan,mar	1980	√	

TEMPERATURE

Bromley : max	jan...dec	1950-1961		√
	jan	1964	√	
	feb,apr	1976	√	
	nov	1982	√	
min	jan...dec	1950-1961		√
	jan	1964	√	
	feb,apr	1976	√	
	nov	1982	√	
	aug	1985	√	
mean	jan...dec	1950-1961		√
	jan	1964	√	
	feb,apr	1976	√	
	nov	1982	√	
	aug	1985	√	

lead to rainfall data being corrected when no correction was required. Thus there is a possibility of the author making errors when using the homogeneity analysis.

3.6 EXTENDING THE RECORD

Some of the sites record lengths were extended by using the BMDP "*Missing Value*" program. This had several advantages as long as the estimated values were checked for reliability by comparison with neighbouring stations. The advantages are:

1) Extending site records both forward and backwards to get a clearer picture of spatial components of any climatic trends/changes.

2) To improve the spatial mapping of rainfall patterns.

3.6 CONCLUSION

Climatic districts were defined before pre-processing the climatic records. These districts were subjectively chosen on the basis of topographic features so that stations with similar climatic records weregrouped together. The climatic records were then examined for homogeneity.

This chapter, with the given examples, has discussed the importance of homogeneity assessment especially when looking at climatic trends/ changes. If the climatic record has missing values and or, incorrect data, the resultant climatic trends/changes shown will have gaps or may give an incorrect picture of actual climatic trends/changes occurring at the stations.

CHAPTER FOUR

BACKGROUND CLIMATOLOGY OF BANKS PENINSULA

4.1 INTRODUCTION

In chapter two the major influences on Canterbury climate were discussed in some detail. General similarities and differences between Banks Peninsula and the Canterbury Plain's climate were briefly examined. Previous studies looking at the Canterbury Plain's climate and weather (Sturman 1986) have included Banks Peninsula by using some of the rainfall stations operating there. However these studies have not looked specifically at Banks Peninsula. The emphasis of this chapter is to present a comprehensive detail of Banks Peninsula's climate.

Because of the nature of the data available in the study area only rainfall, and to some extent temperature, will be looked at. Comparisons will be made between Banks Peninsula stations and the surrounding Plains stations to determine similarities and differences between the two regions.

4.2 RELATIONSHIP WITH CANTERBURY CLIMATE

Like the Canterbury Plains, Banks Peninsula is affected by the Southern Alps being a barrier to moist westerly flows. Consequently it has lower rainfall totals than the West Coast. Because of this mountain barrier most rain-bearing winds come from the southerly quarter, and occasionally from the northeast to easterly quarter. Northwesterly conditions bring warm, dry foehn winds to the Canterbury Plains which also affect Banks Peninsula.The sea has a moderating influence on the coastal Canterbury Plains area reducing the more extreme climatic conditions that occur on the inland parts of the Canterbury Plains. This moderating influence has a more noticeable effect on the Banks Peninsula climate.

Despite these similarities to the Plains, the Banks Peninsula climate does differ significantly. Because the peninsula projects out from the Canterbury Plains, the Southern Alps provides less shelter from rain bearing winds from the south and southwest. This makes Banks Peninsula more exposed to the dominant rain bearing winds from the south and southwest, (Mc Gann 1983). Rainfall totals are therefore generally higher than those found on the Canterbury Plains at similar altitudes. While the Canterbury Plains are uniformally flat and sloping, Banks Peninsula is hilly and rugged with many valleys, making its climate a complex and complicated picture.

The many bays and two harbours allow the sea to penetrate into Banks Peninsula which is largely surrounded by sea. These factors have made the peninsula's climate more moderate than the Canterbury Plain's climate, with more rainfall and less extreme temperatures.

The rainfall and temperature climate will now be discussed.

4.3 CLIMATOLOGY OF BANKS PENINSULA

4.3.1 RAINFALL

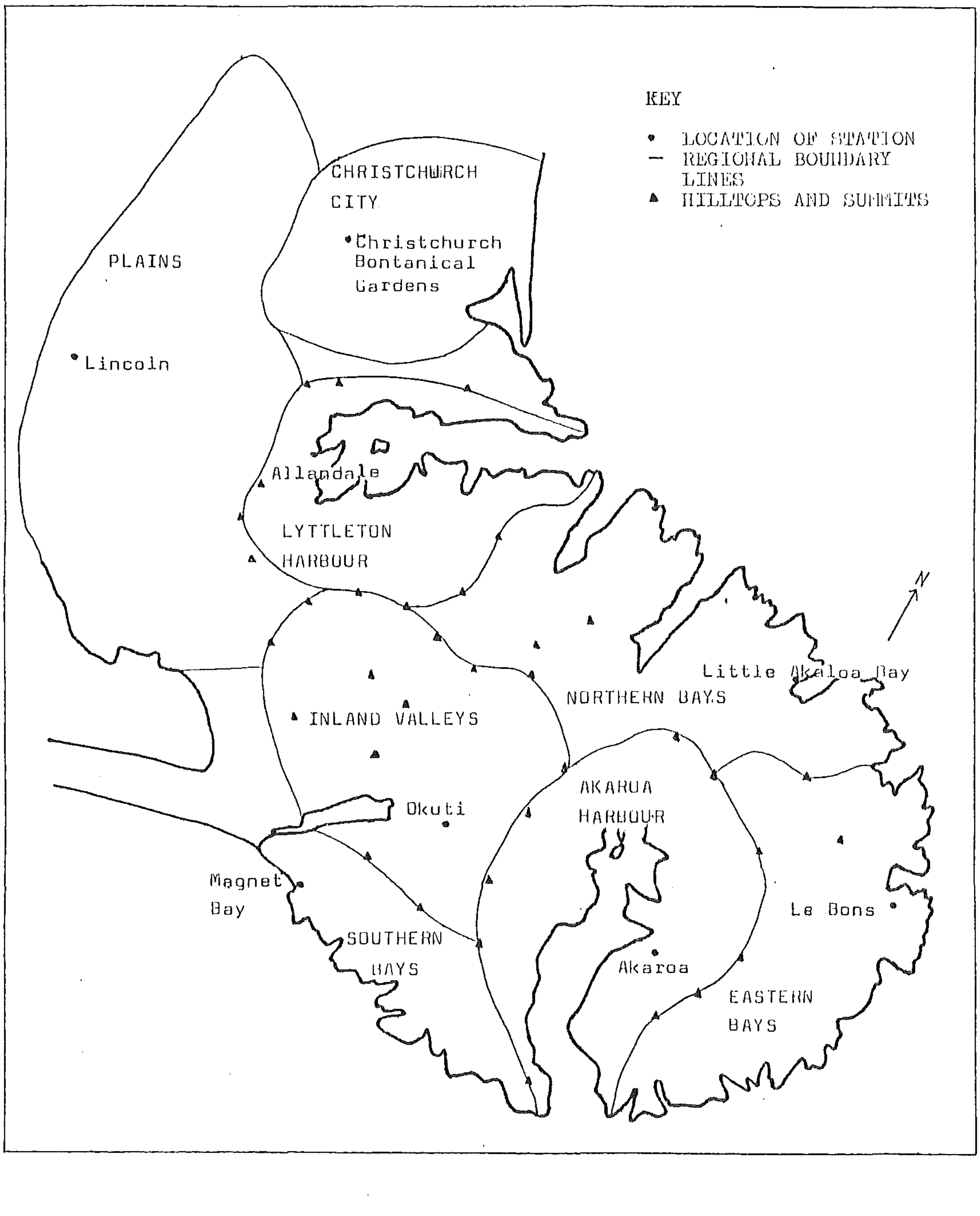
Eight stations (Christchurch, Lincoln, Akaroa, Okuti, Allandale, Magnet, Little Akaloa, and Le Bons Bay) will be used as examples of the rainfall patterns over the study area. Each station represents one of the eight regions drawn up for homogeneity assessment (Figure 4.1).

Rainfall over Banks Peninsula is influenced by three factors:

1) The Southern Alps provides some sheltering effect so that rainfall is relatively lower than the West Coast at similar altitude

2) Exposure to rain-bearing winds from the southwest to the northeast.

FIGURE 4.1 LOCATION OF THE EIGHT REPRESENTATIVE STATIONS



3) The influence of altitude on rainfall distribution over Banks Peninsula.

Annual average rainfall on the surrounding plains area, from Bromley to Greenpark stations, is dominantly less than 650mm. However most of Banks Peninsula generally receives more than 700mm of rainfall a year. Rainfall totals are much higher in the high altitude regions exposed to the south and southwest. Figure 4.2 shows the monthly, extreme maximum and minimum rainfall totals of the eight representative stations over the study area. The figures clearly show that Banks Peninsula climate is dominantly wetter than the surrounding plains areas.

Rainbearing winds

Like the surrounding Plains area, the dominant rain-bearing winds come from the southwest to the northeast. According to Mc Gann (1983), 50 percent of the annual rainfall in Christchurch is associated with southwest winds so Banks Peninsula is likely to show a similar or higher figure. The occasional moist northeast to easterly airstream can also bring significant rainfall to the study area.

Spatial pattern of Banks Peninsula rainfall

The average annual rainfall varies from 565mm at Godley Head Light at the Lyttelton Harbour entrance to more than 1600mm on the

FIGURE 4.2 MONTHLY AND EXTREME RAINFALL TOTALS OVER THE STUDY AREA

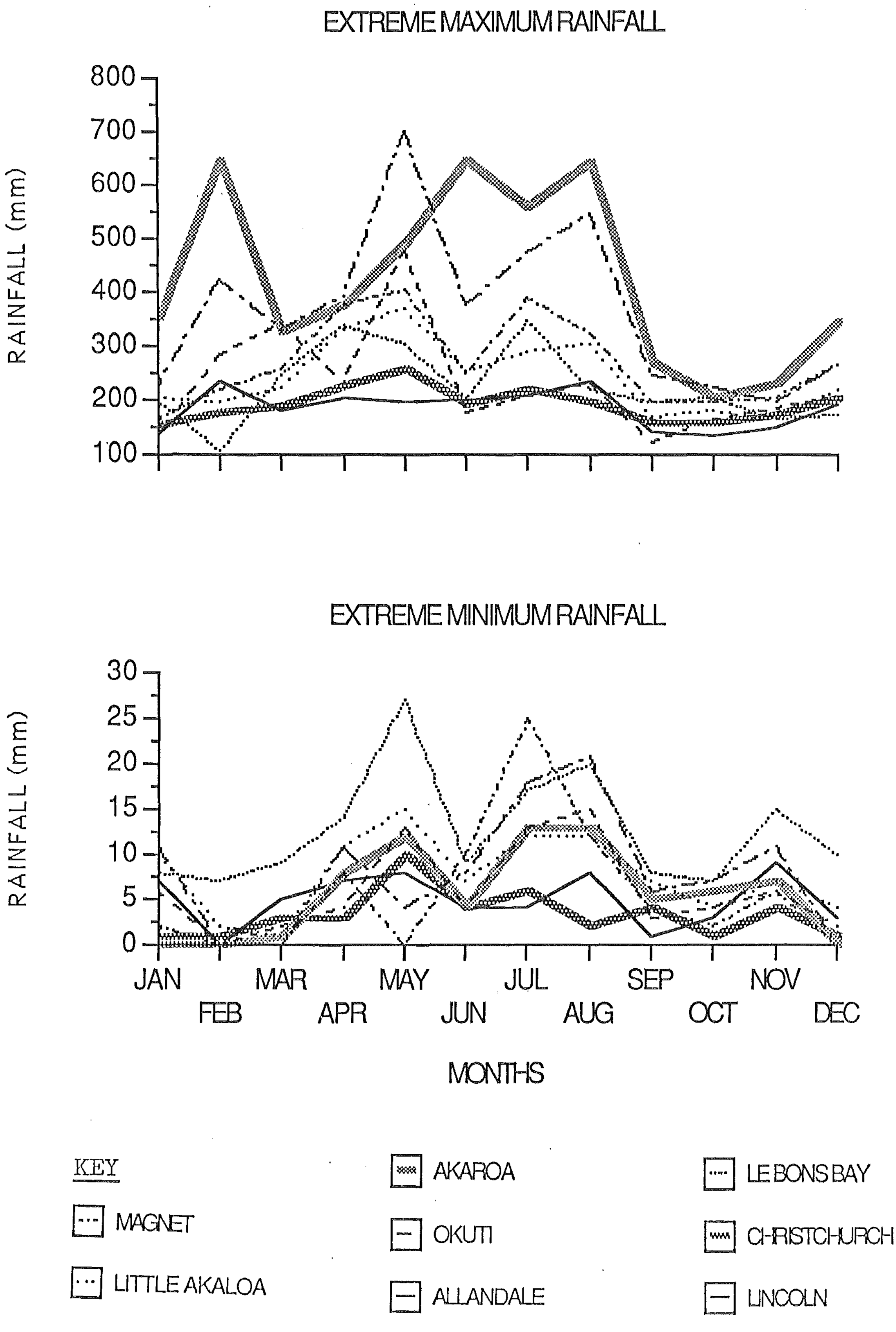
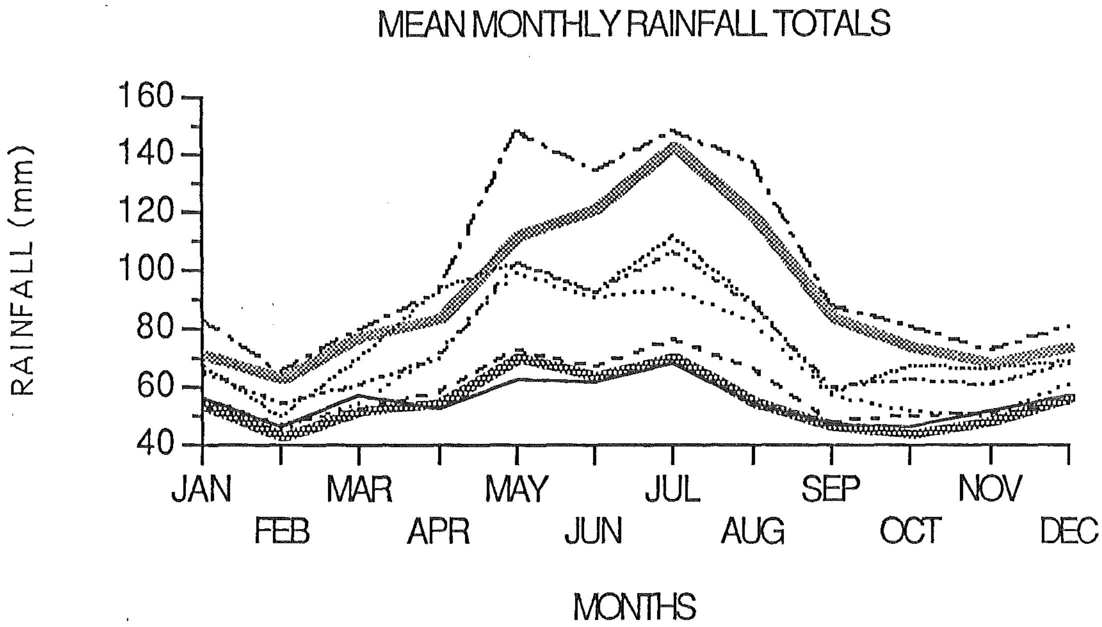


Figure 4.2 continue



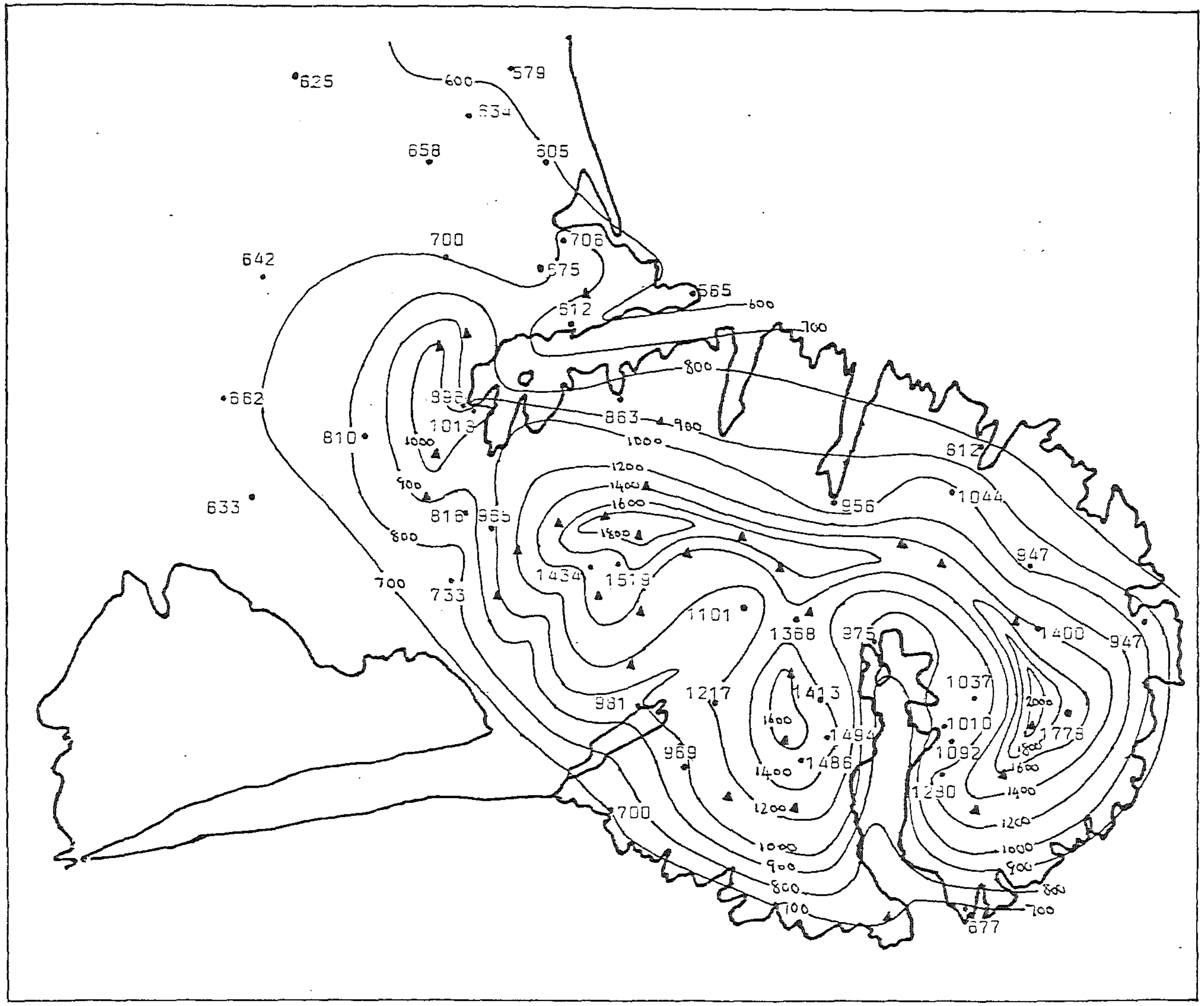


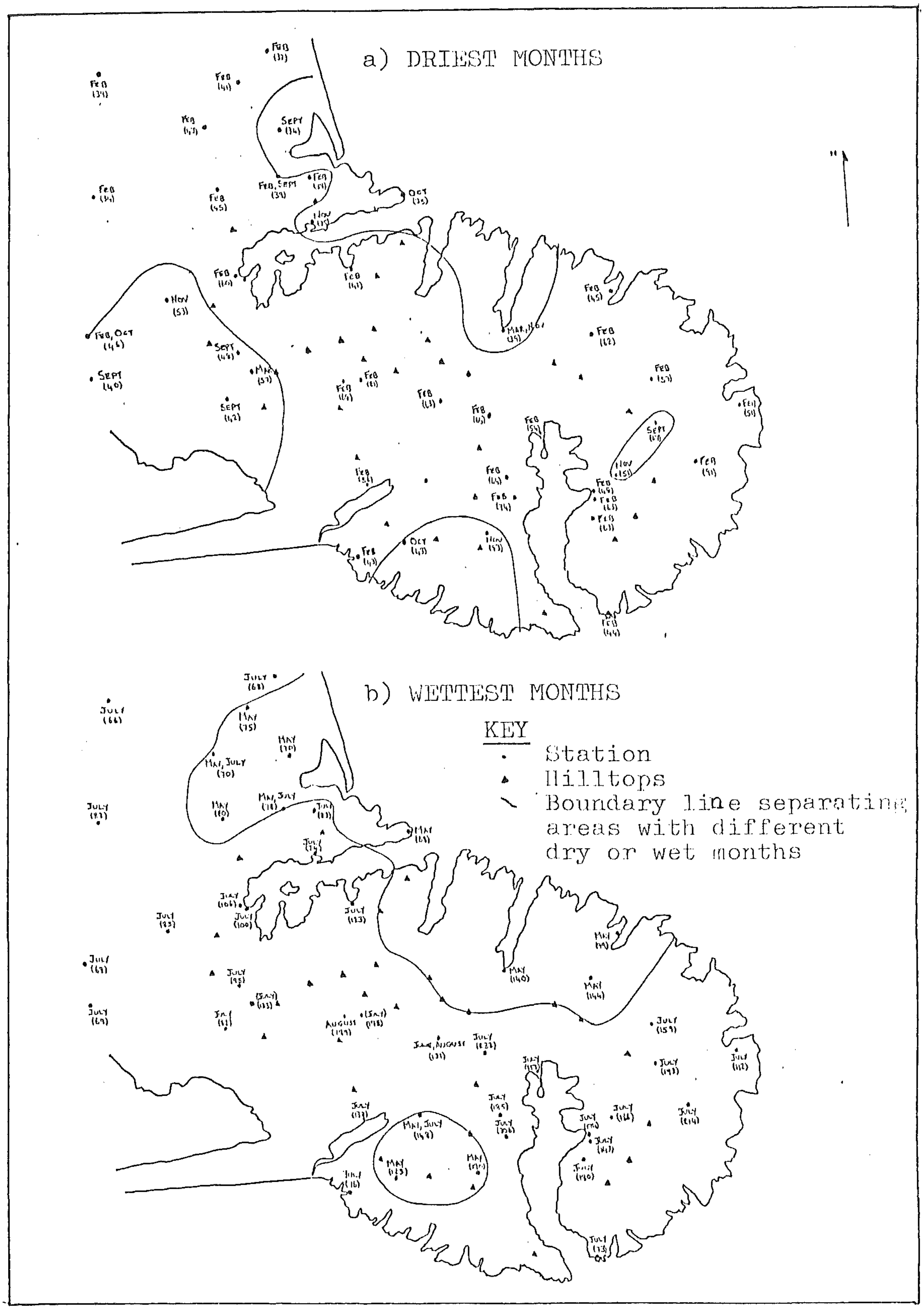
FIGURE 4.3 MEAN ANNUAL RAINFALL OVER THE STUDY AREA

summits and hilltop areas exposed to the south and or, east (Figure 4.3). Christchurch region and northern parts of Lyttelton harbour are in a rain-shadow area when moist winds come from the southeast. Three rainfall peaks occur over Banks Peninsula, two peaks occur near Akaroa Harbour and the other around the Mount Herbert area. The relatively low rainfall totals in the northern bays and the northern side of Lyttelton Harbour compared to other areas of Banks Peninsula seems to indicate that the dominant rain-bearing winds come from the south to southwest airstreams. These two regions would be sheltered to some extent from these rain-bearing winds by the hills to the south.

The lowest rainfall area occurs near the entrance to Lyttelton Harbour. Higher rainfall totals occur over the hills at the western end of Lyttelton Harbour, a result of being exposed to two moisture bearing winds. The easterly winds penetrate up through the harbour while the southerlies penetrate through the relatively low Gebbies Pass area. These two moist bearing winds are forced to flow over the Port Hills at a similar location, the end of Lyttelton Harbour, resulting in higher rainfall totals over this area.

Most stations over the study area have their lowest rainfall totals in February (Fig 4.4). Some stations in the low rainfall areas have a minimum in September; probably the result of increasing

FIGURE 4.4 SPATIAL DISTRIBUTION OF THE WETTEST AND DRIEST MONTHS OF THE YEAR OVER THE STUDY AREA



westerly flows in spring time. The pattern for the month with the highest rainfall total is slightly more complicated. A majority of stations show July as the month of highest rainfall total. These stations are in areas exposed to the south and southwest when rain bearing south to southwesterly airstreams more frequently cross New Zealand. However there is a large minority of stations showing maximum rainfall in May. These stations are dominantly in areas sheltered from the rain bearing south to southwesterly winds. The maximum rainfall in May for these stations may be the result of more frequent occurrence of moist east to northeasterly airflows at this time of the year.

4.3.1.1. Seasonal Rainfall Patterns

Most stations in the study area show a variation of rainfall over the year (Figure 4.2) and on a seasonal basis (Table 4.1). While the surrounding plains area shows a tendency to winter maximum rainfall, most stations over Banks Peninsula have a definite rainfall maximum. Some of the wettest rainfall stations get twice as much rainfall in winter than in the summer period (Table 4.2). In fact some of the high altitude stations would get as much, or more, rainfall in the winter months than some of the driest stations would get in an average year.

All stations show the spring and summer period as being the

TABLE 4:1 SEASONAL RAINFALL

	Summer[1]	Autumn[2]	Winter[3]	Spring[4]
Christchurch	153	177	189	138
Lincoln	159	173	185	145
Akaroa	208	273	382	226
Okuti	230	321	420	242
Allandale	188	234	287	184
Magnet	158	184	209	149
Akaloa	160	226	268	159
Le Bons	187	267	294	191

1 - Dec, jan, feb

2 - Mar, apr, may

3 - Jun, jul, aug

4 - Sep, oct, nov

lowest rainfall period. However there is a distinct difference between the wetter rainfall stations (approximately above 1000mm of rainfall annually) and the drier rainfall stations. Stations with low rainfall totals tend to have their lowest rainfall in spring while stations with high rainfall totals tend to have their lowest rainfall in summer. (Table 4.2). During spring time the westerlies gather strength to reach their maximum in November resulting in low rainfall. However winter conditions can linger on into spring, especially September. This would result in rain-bearing south to southwesterly, which sweep up the South Island more frequently in the winter,but may persist into spring. The higher altitude regions of Banks Peninsula are more likely to be affected by this condition than the lower altitude regions due to topographic forcing of these unstable airmasses. This would result in higher altitude regions, which have generally high rainfall totals, having higher rainfall totals in spring than in the summer while low altitude regions have their lowest rainfall in spring. The summer period is dominated by anticyclonic conditions over New Zealand resulting in high (wetter stations) altitude regions having their lowest rainfall totals at this time of the year. With the lessening of the westerlies in summer, moister winds from the east through to the south more frequently flow across New Zealand than in the spring time.

TABLE 4:2 COMPARING SEASONAL RAINFALL TOTALS BETWEEN REGIONS OF HIGH RAINFALL AND LOW RAINFALL (mm)

	Summer	Autumn	Winter	Spring
HIGH RAINFALL REGIONS				
Hickory Bay	316	519	606	322
Tophouse	283	420	518	298
French Farm	247	328	513	300
Okuti	230	321	420	242
LOW RAINFALL REGIONS				
Godley	128	163	170	109
Akaroa Heads	141	191	201	140
Gebbies Pass	180	222	248	158
Lyttelton	135	169	202	108

<u>Summer period</u>

Appendix (1) shows the monthly rainfall patterns over the study area during the summer months while Figure (4.5) shows the summer rainfall distribution at 50mm intervals. During the summer period, rainfall totals decrease from December through to February. Few stations have one or more months with an average rainfall total of more than 100mm. The maximum peak on the western side of Akaroa Harbour is further south and closer to Akaroa Harbour entrance than in the winter months (Figure 4.6). The three maximum rainfall regions become more isolated as the linkages between the three peak rainfall regions have broken down as shown in Appendix (1). Spacing between the rainfall isolines (gradient) is wider than in the other three seasons suggesting the differences between stations with high and low rainfalls are less (Figures 4.5 and 4.6).

The slight rainfall maximum region around the western end of Lyttelton Harbour (Port Hills) is the result of topographic forcing of rainbearing southerlies and northeasterlies.

The driest area during the summer months is the area around the entrance of Lyttelton Harbour and the coastal areas of Christchurch city. These two areas show up as being the driest regions in all months of the year as well as the seasons and annual totals.

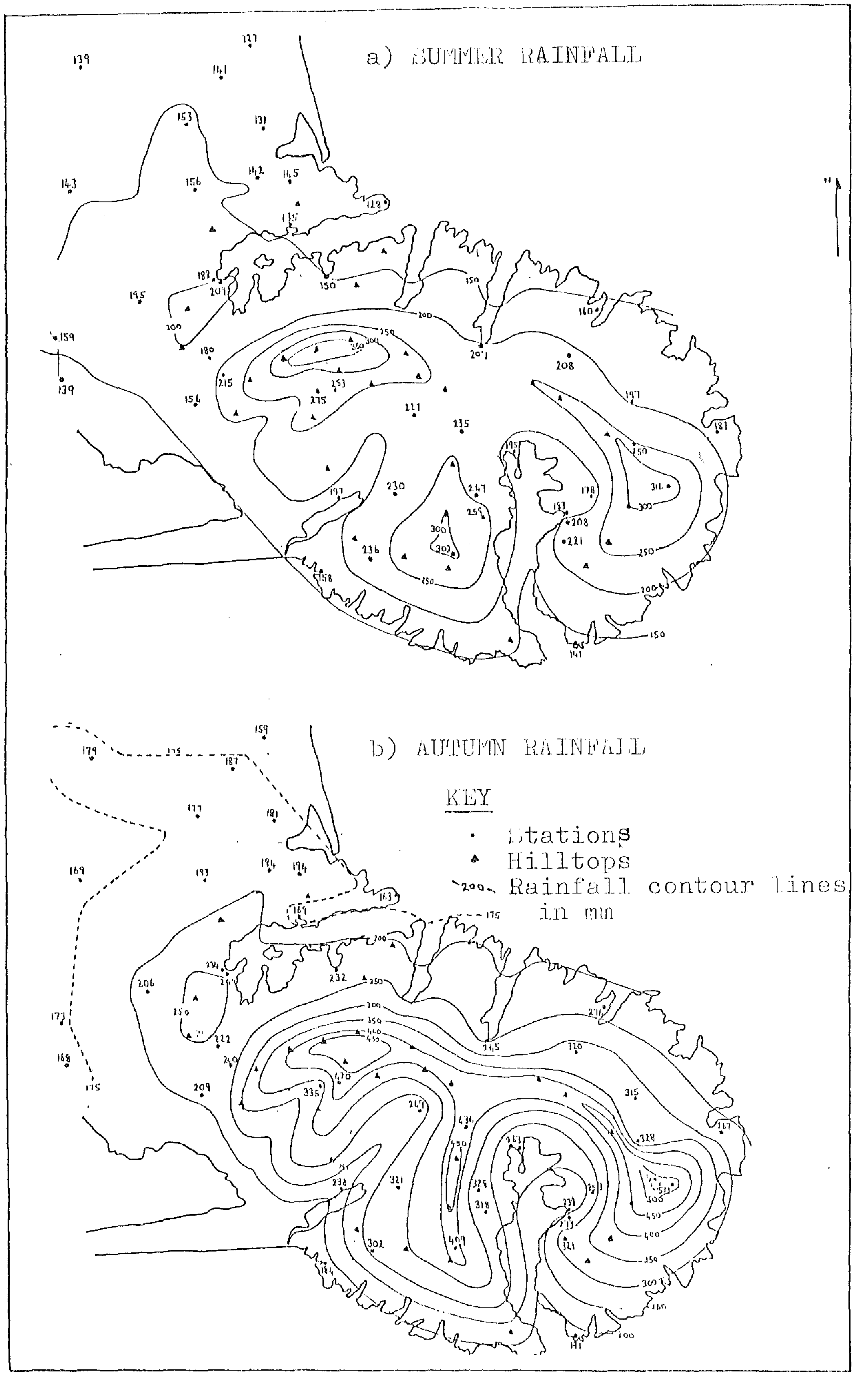
Autumn period

Monthly rainfall totals during autumn are larger as the months progress from March to May (Appendix 1). This is probably the result of regular occurrence of rain bearing south to southwest winds moving up over New Zealand as winter approaches. The spacing between the rainfall isolines becomes closer from March to May. The three peak rainfall areas become more distinct, larger, and start to link up. The peak rainfall region over the western side of Akaroa Harbour moves back towards the northern end of harbour.

The difference between the low rainfall and high rainfall regions becomes larger. For instance compare the autumn rainfalls of the surrounding plains to Banks Peninsula (Figure 4.5). Akaroa station receives on average 273mm of rainfall in Autumn while Christchurch Airport receives on average 179mm of rainfall. Both are at similar altitudes.

An interesting rainfall pattern occurs in May over Lyttelton Harbour. Approximately 110mm of rainfall occurs at the western end of Lyttelton Harbour, an area exposed to rain bearing southerlies and northeasterlies. Moving towards the harbour entrance, rainfall totals drop to about 60 to 70mm. This indicates that this area is sheltered from the southerlies by the hills to the south but still exposed to the northeast. Rainfall also decreases from south to north across

FIGURE 4.5 SUMMER AND AUTUMN RAINFALL TOTALS OVER THE STUDY AREA



Lyttelton Harbour. Most months and seasons show this trend.

Winter period

This is the season of maximum rainfall totals for all stations when rain bearing southeasterly to southwesterly winds regularly sweep over New Zealand bringing cold wintry rain showers. Snow usually falls on the higher ground of Banks Peninsula. The peaks and summits of Banks Peninsula help to intensify the rainfall by topographic forcing of already unstable moist airmasses from the southerly quarter. The disparity between the surrounding Plains rainfall and Banks Peninsula rainfall is at its greatest in July (Appendix 1) and in the winter season (Figure 4.6). For instance a large majority of the Banks Peninsula area receives on average of more than 300mm of rainfall in winter while the surrounding plains area receives between 170 to 190mm of rainfall. At similar altitudes on Banks Peninsula, the average winter rainfall is dominantly above 200mm. Some parts of Banks Peninsula receive more rainfall in the winter season than the stations in the low rainfall regions receive for a whole year (Figures 4.3, 4.6).

Around Akaroa Harbour a steep rainfall gradient occurs from sea level to the hilltops surrounding the harbour. At sea level the average rainfall is approximately 350mm while the surrounding hilltops can receive over 500mm of rainfall.

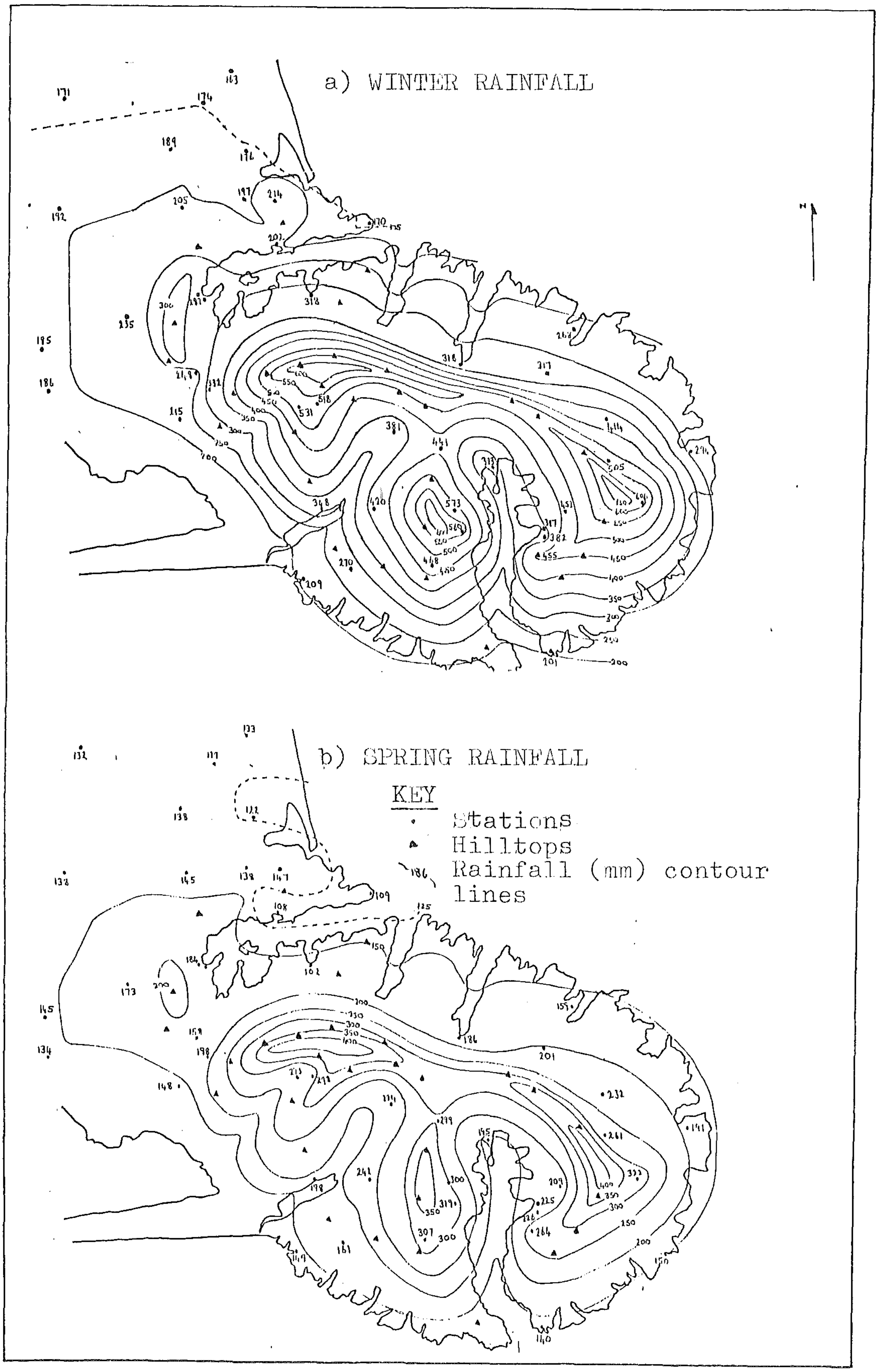
Because of the sheltering effect of Banks Peninsula hills the lowest rainfall totals occur around Lyttelton Harbour entrance and the coastal parts of Christchurch city (Figure 4.6).

Spring period

Appendix (1) shows the spatial patterns of monthly rainfall distribution over the study area in spring while Figure 4.6 shows the spring rainfall pattern at 50mm intervals. Winter conditions give way to spring conditions which are usually indicated by the strengthening of the westerlies. This condition is indicated by the low rainfall totals in the surrounding plains areas and drier regions of Banks Peninsula. The low rainfall totals for this period are probably the result of the westerlies losing their moisture over the Southern Alps with the Canterbury Plains being in the rain shadow area.

The low altitude regions of Banks Peninsula and the surrounding plains record their lowest seasonal rainfall totals in spring while the higher altitude regions lowest rainfall totals in summer. This may indicate that the strengthening of the westerlies in the early part of spring are more orientated to the west to southwesterly direction than to the west to northwesterly direction. This would result in Banks Peninsula being more exposed to showery southwesterly airstreams than the surrounding plains. Also conditional instability would be experienced in west to southwesterly airflows wth Banks

FIGURE 4.6 WINTER AND SPRING RAINFALL OVER THE STUDY AREA



Peninsula acting as the trigger mechanism. The airmass would be forced to rise over Banks Peninsula creating instability conditions, allowing convective clouds to develop and produce showers over Banks Peninsula. Most of these showers would occur over the hilltops of Banks Peninsula due to topographic forcing of unstable southwesterly airflows than in the valley bottoms and coastal regions of the peninsula.

The peak rainfall areas become less distinct with the lessening of rainfall totals. The region of high rainfall on the western side of Akaroa Harbour becomes enlongated as it moves back towards the harbour entrance.

4.3.1.2 Rainfall Variability

Variability ((standard deviation/mean)*100%) looks at the variation of rainfall at each station. The higher the rainfall variability, the more extreme rainfall totals occur at the station. The higher rainfall variability also indicates less reliability of rainfall totals at given stations.

Annual rainfall variability varies from 16.3% to 28.6%. Figure 4.7 shows the spatial distribution of rainfall variability over the study area. Low rainfall variablity, below 20%, occurs on the plains southwest of Banks Peninsula and north of Christchurch. High rainfall variability, above 25%, occurs on the hills surrounding Akaroa Harbour, and around Lyttelton Harbour east of Quail Island. The causes of these two higher rainfall variability areas are probably related to the following:

1) Canterbury frequently experiences dry spells which result in drought conditions occurring on a regular basis. These dry spells are likely to affect Banks Peninsula at the same time resulting in sharply reduced rainfall totals over the study area. Rainfall totals would be similar over the study area in drought conditions. However in wet periods, rainfall totals are likely to be much higher over high altitude regions of Banks Peninsula in comparison to the rest of the study area. This would explain the higher rainfall variabilities around the Akaroa Harbour region.

2) Canterbury also experiences wet periods when rain bearing airstreams more frequently flow over the Canterbury region. The 1974-1980 period is one example when moist east to northeasterly airflows were more frequent. Lyttelton Harbour would be exposed to these moisture bearing airstreams therefore sharply increasing rainfall totals in this dry region. This would result in higher rainfall variability over this area.

Figure 4.8 shows monthly rainfall variability of the eight representative stations over the study area. All stations have rainfall

FIGURE 4.7 ANNUAL RAINFALL VARIABILITY

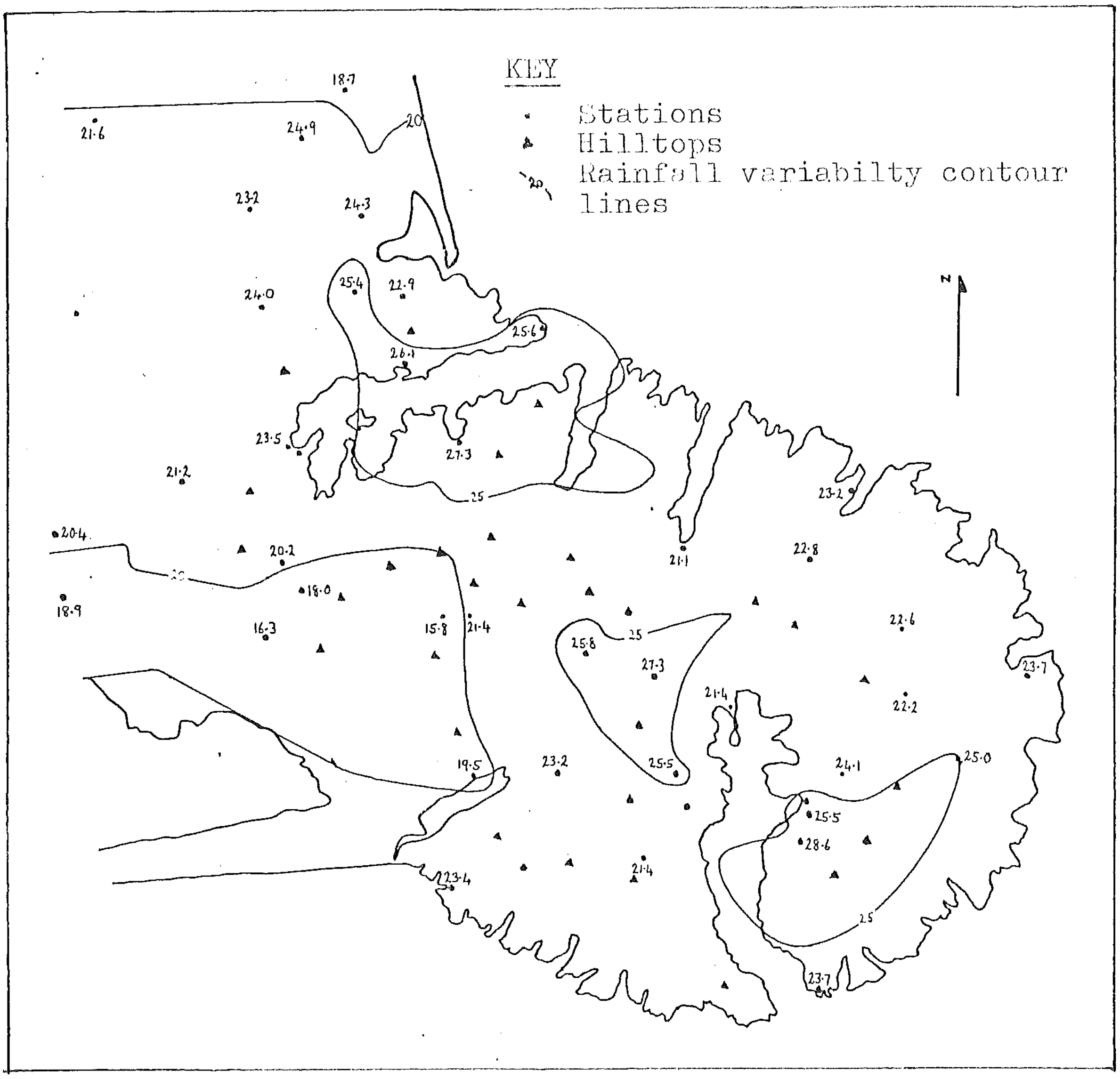
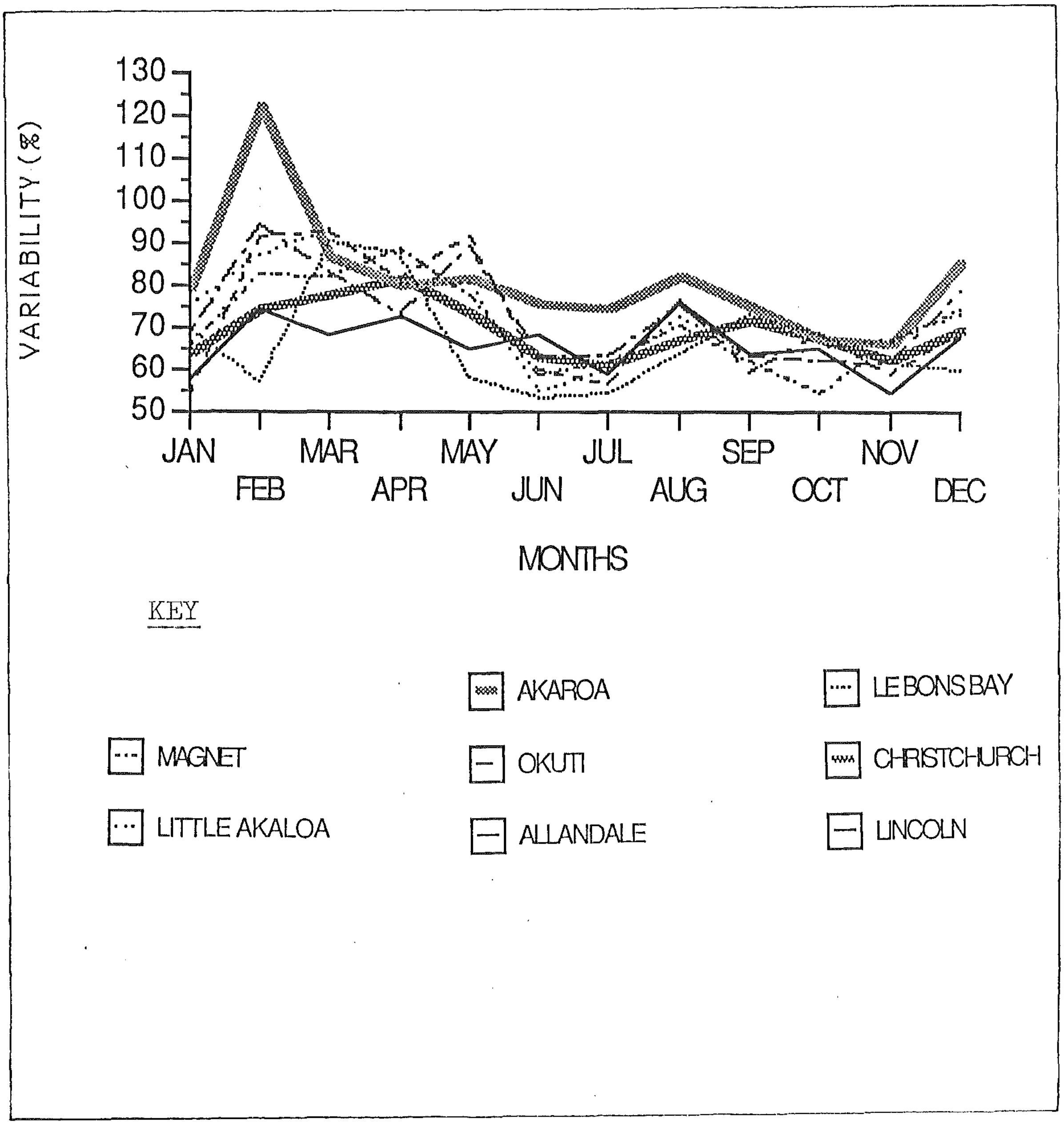


FIGURE 4.8 MONTHLY RAINFALL VARAIABILITY OF THE EIGHT REPRESENTATIVE



variability above 50% for all months of the year. High rainfall variability occurs in the months February to May. Possible causes for this are:

1) Increased frequency of rain bearing southerly quarter winds occurs from February to May (see Chapter 6). This would result in increased convective activity as well. However the timing of this increase would vary from year to year.

2) Cyclonic activity also increases from February to May but the timing of this increase would vary fom year to year.

3) More convective activity in summer causing both spatial and temporal variability.

Relatively low rainfall variability occurs in spring. This may suggest that the strengthening of the westerlies over New Zealand is relatively consistent year after year in spring.

4.3.1.3 Altitudinal Effects on Rainfall

In the Mid-latitude zones precipitation increases with altitude to around about 3000 to 3500 metres above sea level. Forced ascent is believed to cause most of the precipitation rather than the thermally-induced convection. This rainfall type is known as orographic.

Rainfall on Banks Peninsula suggests a positive relationship with height above sea-level. However, this relationship varies over the area as a result of exposure to the dominant rain bearing winds. So when statistical tests were used to establish if rainfall does significantly increase with altitude over Banks Peninsula this factor had to be taken into account.

Product moment correlation was used to test the correlation of rainfall against altitude. Student's '*t* ' test was used to determine the significance of the results at the 5% and 1% levels. Linear regression equations were determined for each tested region.

Table 4.3 shows the results of the test. Southern Bays, Inland Valleys, Eastern Bays, and Northern Bays were not tested because of lack of stations. Christchurch was significant at the 5% and 1% level while Akaroa was significant at the 5% level. This probably indicates two that:

1) More stations are required to statistically prove that rainfall increases with height at the 1% level.

2) The regions used for this analysis are still too broad, and smaller regions are required because of the varying rainfall totals at similar altitudes over the study area.

However the results indicate that rainfall increases with height. Figure 4.9 shows the regression lines for each tested region.

TABLE 4.3: REGIONAL RESULTS OF CORRELATION ANALYSIS COMPARING RAINFALL AGAINST ALTITUDE

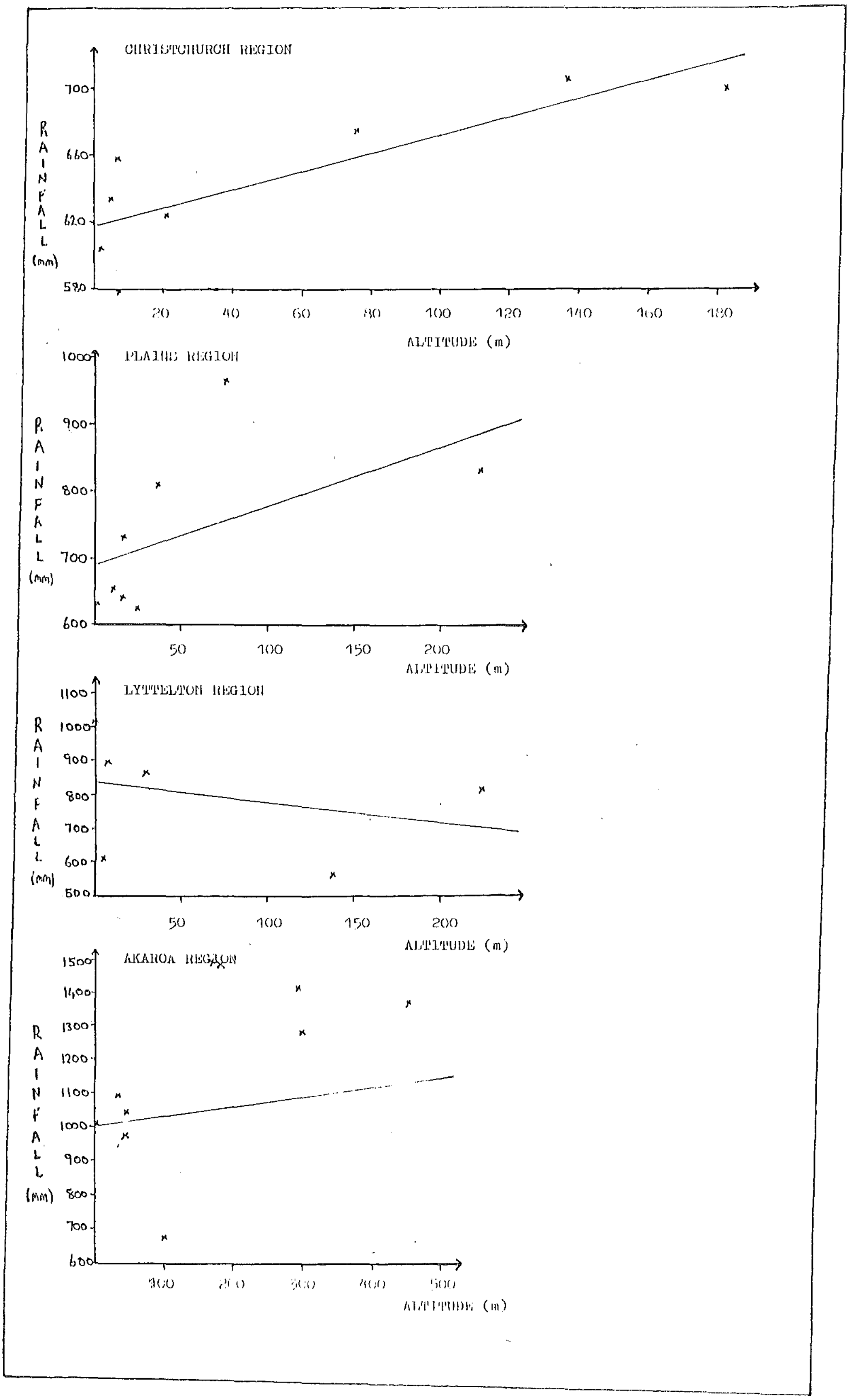
REGION	NUMBER OF STATIONS	R	R^2	*t* TEST	SIGNIFICANT AT 5%	SIGNIFICANT AT 1%
Christchurch	8	0.837	0.701	3.75	Y	N
Plains	8	0.534	0.285	1.55	N	N
Lyttelton	6	-0.312	0.097	-0.66	N	N
Akaroa	10	0.613	0.357	2.19	Y	N

REGRESSION LINES FOR EACH OF THE TESTED REGIONS

Christchurch	$Y = 618 + 0.54X$
Plains	$Y = 692 + 0.87X$
Lyttleton	$Y = 835 + (-0.59)X$
Akaroa	$Y = 1001 + 0.28X$

Y = rainfall   X = altitude

FIGURE 4.9 LINEAR REGRESSION LINES OF THE FOUR TESTED REGIONS COMPARING RAINFALL AGAINST ALTITUDE



4.3.2 TEMPERATURE

Only nine stations have recorded temperatures in the study area of which five are located on the peninsula. The stations at Quail Island in Lyttelton Harbour, and Catons Bay opposite Lake Foresyth have been operating for less than 5 years so were not considered for climatological analysis. Despite the lack of temperature data, a comparison can be made between Banks Peninsula and the surrounding plains area. The stations record length have been used to determine temperature averages and the spatial patterns

4.3.2.1 Annual Temperature

Mean annual temperature (Table 4.4) shows that Banks Peninsula climate is warmer than the surrounding plains area by up to 1.4 ºC. The coldest part of the plains is around Lincoln probably due to more exposed position to the southerlies and reduced moderating effect of the sea. The coastal parts of Christchurch City is the warmest parts of the plains due to the moderating influence of the sea and being somewhat sheltered from the southerlies.

Mean annual maximum temperature (Table 4.4) shows little variation over the plains apart from a slight tendency to milder temperatures away from the coast. Mount Pleasant station, at 183m above sea level, has the coldest maximum temperature due to its height and stronger winds experienced at higher altitudes. Maximum temperatures in Akaroa Harbour are warmer than those on the plains. Akaroa's 17.6 ºC (began operating in 1978) probably relates to the warmer temperatures that Canterbury has experienced recently. Christchurch's mean annual maximum temperature for the 1978-1985 period is 17.2ºC.

Mean annual minimum temperatures (Table 4.4) show great variation over the study area. Banks Peninsula minimum temperatures are much warmer than the surrounding plains area at similar altitudes. The relatively warm minimum temperatures at Mount Pleasant probably relate to the inversion layer. Inversion layers form in stable airmasses when clear calm nights frequently occurs. Radiational cooling of the ground and the adjacent air occur on these nights. This results in a positive lapse rate (increase temperature with height) which is characteristic of inversion layers. Inversion layers frequently form on the Canterbury Plains under anticyclonic conditions in the colder months of the year. The katabatic drainage of cold air from the mountains down to the coast is the possible reason for the cooler minimum temperatures experienced on the plains as well as radiational cooling at night. Banks Penisula hills would also act as a barrier to this pool of cold air. The warmer minimum temperatures over Christchurch relate to the moderating influence of the sea and the urban heat island effect.

TABLE 4.4: MONTHLY AND ANNUAL TEMPERATURES (ºC) OF SEVEN STATIONS OVER THE STUDY AREA

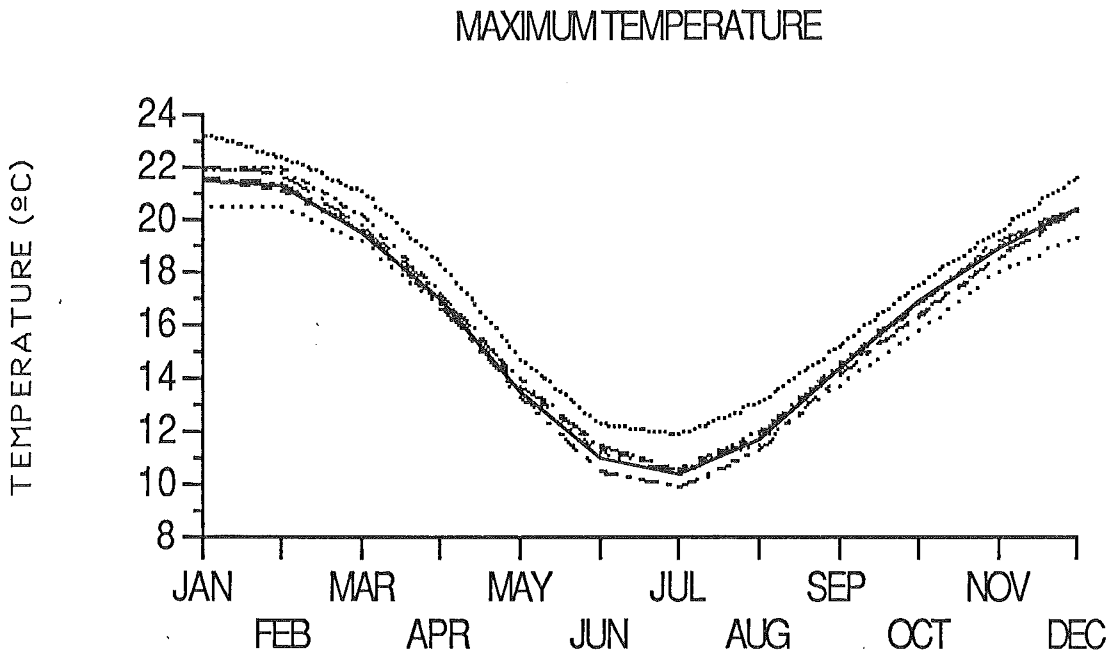
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
MEAN													
<u>Maximum</u>													
Christchurch	21.5	21.3	19.5	17.0	13.5	11.0	10.4	11.8	14.4	16.9	18.9	20.5	16.4
Lincoln	21.7	21.4	19.6	16.8	13.3	10.6	9.9	11.3	14.1	16.5	18.6	20.5	16.4
Airport	22.0	21.8	19.8	17.2	13.8	11.1	10.5	11.9	14.4	16.8	19.2	20.5	16.6
Bromley	21.5	21.1	19.7	16.9	13.8	11.3	10.7	11.9	14.3	16.3	18.6	20.3	16.3
Mt Pleasant	20.6	20.6	19.2	16.7	13.6	11.2	10.6	11.5	13.8	15.8	18.0	19.3	15.9
Omawe	21.9	22.0	20.2	17.2	14.0	11.4	10.6	12.0	14.6	16.9	19.0	20.5	16.7
Akaroa	23.3	22.5	21.1	18.3	14.8	12.3	11.9	13.1	15.2	17.5	19.6	21.7	17.6
<u>Minimum</u>													
Christchurch	11.6	11.5	10.2	7.4	4.2	1.7	1.4	2.5	4.7	6.8	8.5	10.5	6.8
Lincoln	10.4	10.4	9.1	6.3	3.6	1.2	0.9	2.0	3.5	5.6	7.0	9.2	5.8
Airport	11.8	11.6	10.2	7.0	3.8	1.1	0.7	2.0	4.1	6.3	8.6	10.7	6.5
Bromely	12.7	12.7	11.5	8.6	5.6	2.8	2.6	3.7	5.7	7.6	9.5	11.6	7.9
Mt Pleasant	12.5	12.7	11.8	10.0	7.3	5.3	4.7	5.2	6.5	8.0	9.5	11.7	8.8
Onawe	12.2	12.2	11.2	8.8	6.6	4.3	3.8	4.4	6.1	7.6	9.1	10.8	8.1
Akaroa	11.4	11.3	10.6	7.8	4.9	2.2	2.7	2.7	4.7	6.6	8.6	10.7	7.4
<u>Mean</u>													
Christchurch	16.6	16.4	14.9	12.2	8.9	6.3	5.9	7.1	9.5	11.8	13.7	15.5	11.6
Lincoln	16.0	15.9	14.4	11.6	8.5	5.9	5.4	6.7	8.8	11.1	12.9	14.8	11.0
Airport	16.9	16.7	15.1	12.1	8.8	6.1	5.7	7.0	9.3	11.6	13.9	15.6	11.6
Bromley	17.2	16.9	15.6	12.8	9.7	7.1	6.7	7.8	10.0	12.0	14.2	15.8	12.2
Mt Pleasant	16.6	16.7	15.5	13.4	10.4	8.3	7.6	8.4	10.1	11.9	13.8	15.5	12.4
Onawe	17.1	17.1	15.7	13.0	10.3	7.9	7.2	8.2	10.5	12.2	14.0	15.7	12.4
Akaroa	17.4	16.9	15.9	13.0	9.9	7.3	7.4	7.8	10.0	12.0	14.2	16.0	12.3

Figure 4.10 shows the monthly maximum, minimum, and mean temperatures for the seven stations. The graphs clearly indicate that winter temperatures over Akaroa Harbour are much warmer than the surrounding plains, especially minimum temperatures. The shallow waters of the harbour liberating heat stored up in the summer may be the reason for this.

4.3.2.2 Seasonal Temperatures

As shown with the monthly temperatures, the seasonal temperatures over Banks Peninsula are warmer than the surrounding plains in all four seasons. The difference in temperature between the stations is least in the summer and greatest in the winter. Greater mixing of the air mass occurs in summer and by day rather than in the winter and night. This greater mixing is caused by thermal turbulence (rising bubbles of heated air) and local wind systems such as the sea breeze and valley winds. This would result in uniformity of air temperature at differing altitudes. In winter solar energy from the sun is weaker resulting in weaker turbulence while at night heat is losted by radiational cooling. This greatly reduces turbulence and allowing stratification of the air layers to occur. Also the drainage of cold air frequently occurs at night on the plains in the winter. Stagnant pools of cold air would occur over the plains. Temperature variations over the study area in winter would be enhanced in complex

FIGURE 4.10 MONTHLY MAXIMUM, MINIMUM, AND MEAN TEMPERATURES AT SEVEN STATIONS



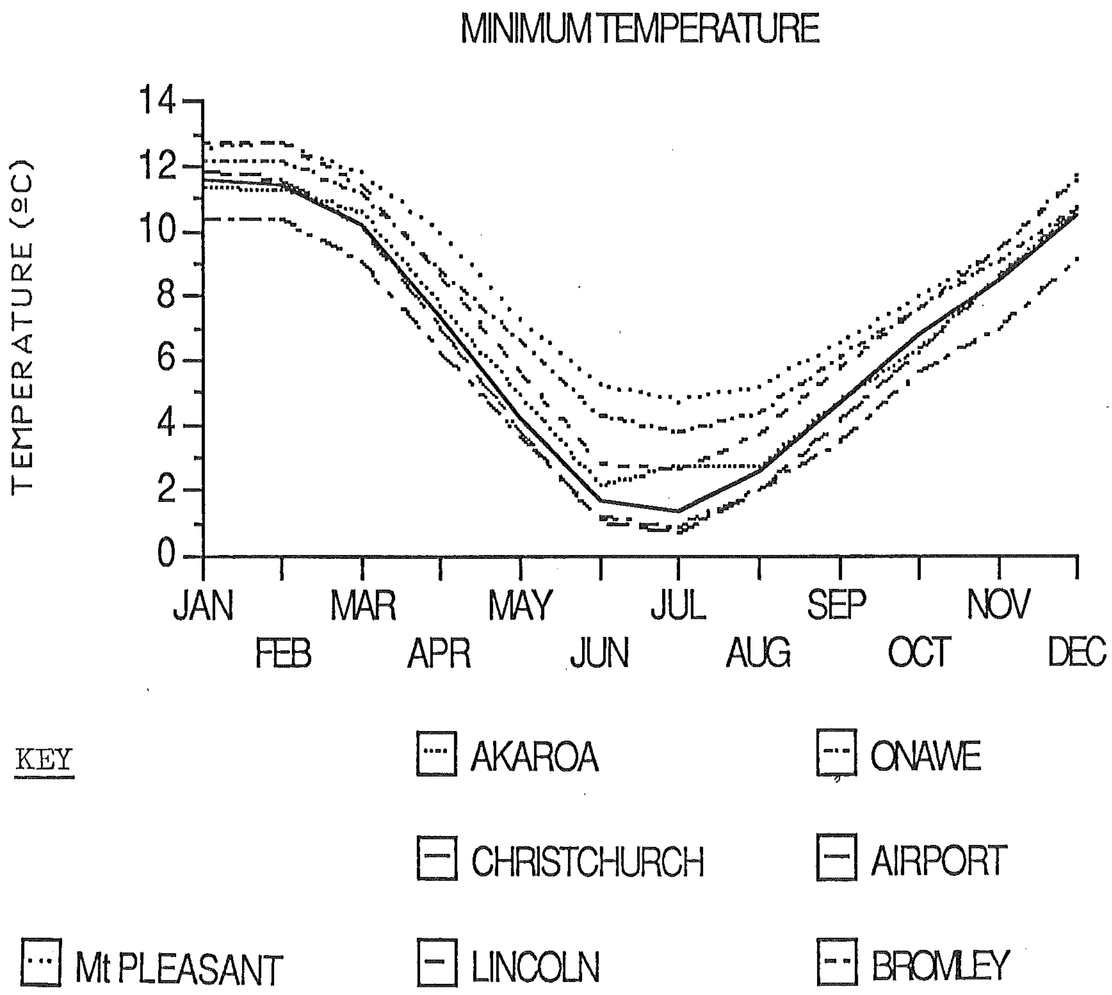
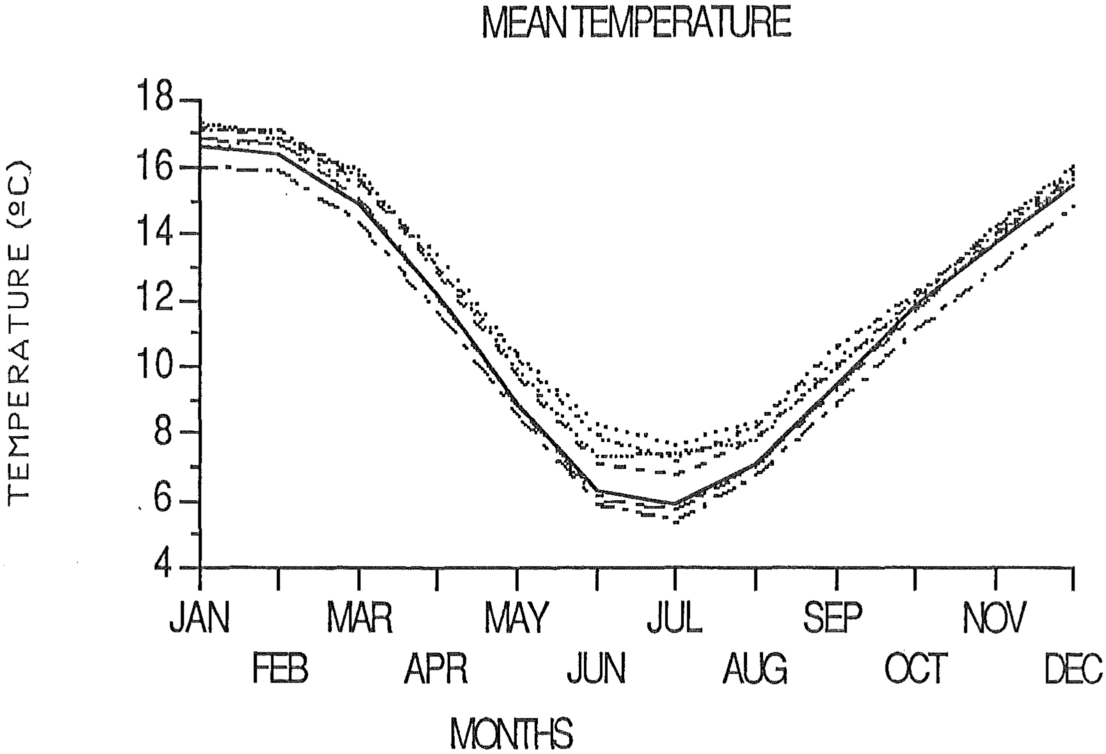


Figure 4.10 continue



terrain, especially at night. Table 4.5 shows the seasonal temperatures.

4.3.2.3 Variability of temperature

The variability technique used in rainfall is also used here. Figure 4.11 shows the monthly maximum, minimum, and mean variability of temperature. Minimum temperature shows the greatest variability while maximum temperature shows the least variability. In terms of seasonal variability the summer months show the least variability while the winter months show the greatest variability, especially minimum temperatures.

During the colder months the plains area have a greater temperature variability than the Banks Peninsula stations. This is particularly so for the minimum temperatures. Lincoln and Christchurch Airport stations have up to and above 100% variability in minimum temperatures during June and July. Two possible factors have been put forward by the author which may be responsible for explaining the higher minimum temperature variability in the colder months:

1) The frequency of cold bearing southwesterlies flowing over the South Island during the winter. These airflows are frequently windy and turbulent. These conditions would result in the vertical and horizontal mixing of the air reducing temperature extremes between

FIGURE 4.11 TEMPERATURE VARIABILITY OF SEVEN STATIONS OVER THE STUDY AREA

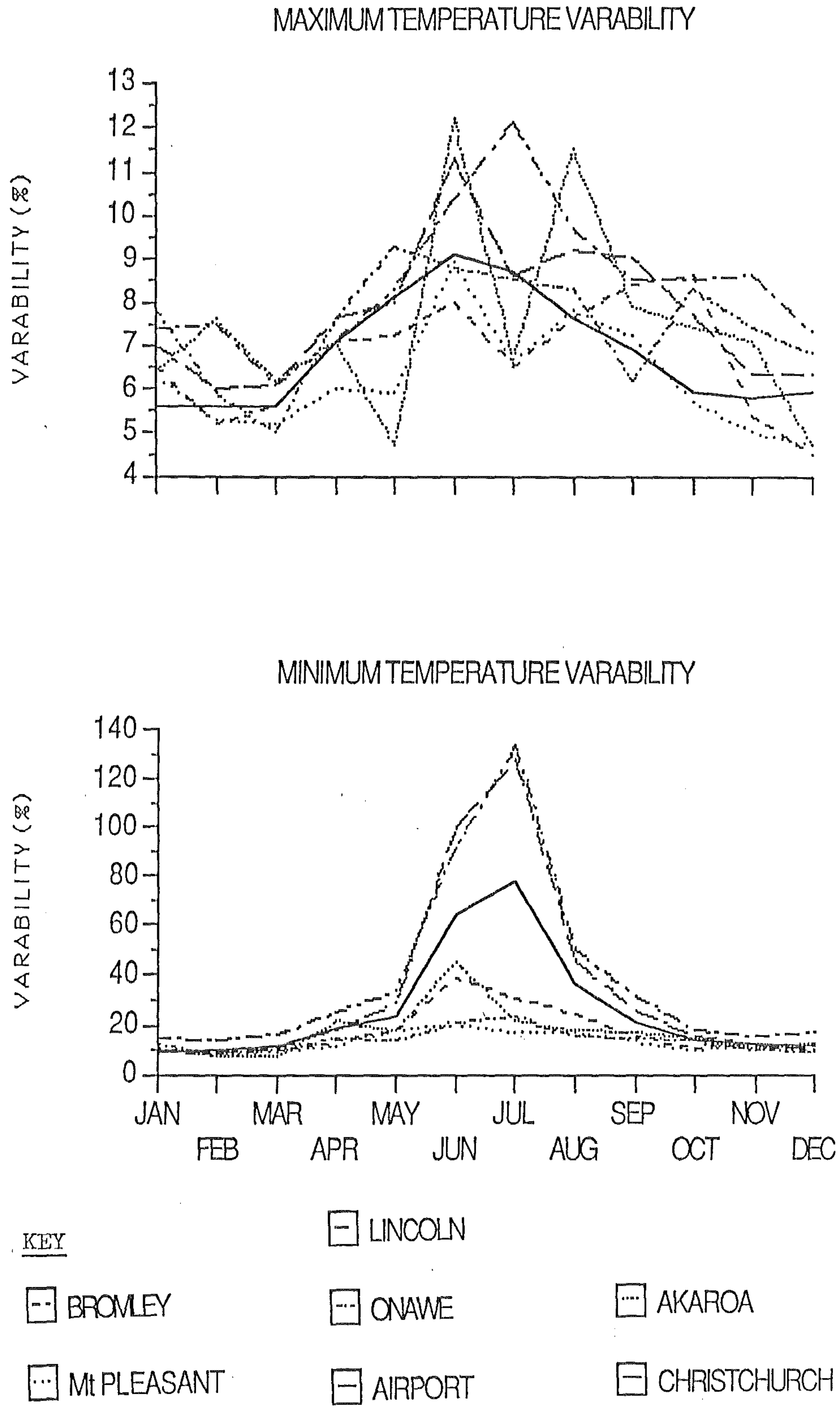
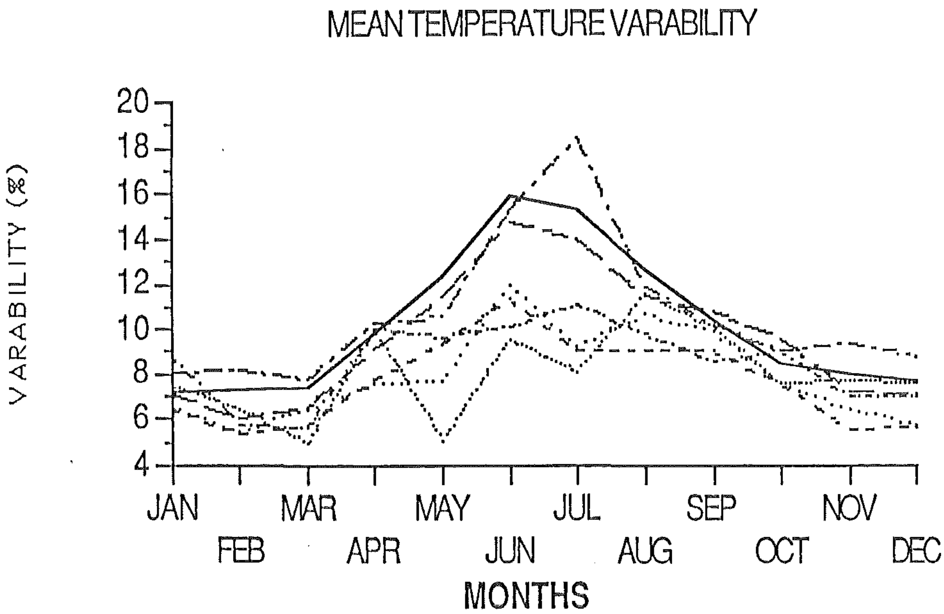


Figure 4.11 continue



the air layers. Cloudy conditions are usually experienced under these airflows which keeps minimum temperature warmer.

2) The number of clear calm nights during the colder months. These conditions form under stable air masses which reduces turbulence in the air. Radiational cooling of the land occurs at night leading to inversion layers being formed as well as katabatic drainage of cold air down the plains. These conditions result in cold frosty mornings.

Statistical tests could be used to determine if these factors are significant.

These factors and are more likely to effect the surrounding plains area than Banks Peninsula because of its flat topography. The hilly nature of Banks Peninsula and the surrounding ocean seems to moderate (reduce) minimum temperature variability as shown by stations in Akaroa Harbour. The release of heat from sea water in the bays and harbours of Banks Peninsula in winter may also be a factor.

4.3.2.4 Extremes

The surrounding plains area has a more extreme climate than Banks Peninsula, especially away from Christchurch city. Table 4.5 shows the monthly extreme maximum and minimum temperatures.

TABLE 4. 5.: HIGHEST AND LOWEST RECORDED MONTHLY TEMPERATURES (ºC) AT CHRISTCHURCH, LINCOLN, AND ONAWE

NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HIGHEST												
Christchurch	36.2	41.6	33.4	30.1	27.0	22.5	22.8	23.2	27.3	31.4	32.2	35.0
Lincoln	37.9	40.4	33.9	29.8	29.7	22.7	20.6	22.2	31.1	30.7	32.8	36.9
Onawe	35.0	35.6	32.8	31.1	26.2	22.3	19.6	21.0	24.3	29.1	32.2	35.6
LOWEST												
Cristchurch	1.1	1.2	-0.9	-3.6	-5.9	-5.8	-7.1	-5.0	-4.8	-3.3	-1.5	0.6
Lincoln	0.1	0.3	-1.9	-4.4	-6.3	-7.1	-11.6	-6.9	-7.2	-5.9	-2.7	-1.2
Onawe	3.3	5.0	2.8	-0.6	-1.1	-2.6	-1.8	-2.1	-0.9	0.0	0.0	4.4

4.4 CONCLUSION

Banks Peninsula has many similarities to the Canterbury Plains climate such as the controlling factor of the Southern Alps on rainfall and temperature. However, Banks Peninsula was found to differ significantly due to two factors:

1) The peninsula projects out from the Canterbury Plains making it more exposed to moisture bearing winds from the southwest to the northeast.

2) Altitudinal effects on rainfall distribution over the peninsula. This has made Banks Peninsula climate wetter than the surrounding plains area at similar altitudes.

Great variations in rainfall totals occur over the study area. The driest region occurs over Lyttelton Harbour entrance with less than 600mm of rainfall a year while the hilltops can receive up to 2000mm of rainfall. Lyttelton Harbour indicates the complex rainfall distribution that occurs over the peninsula due to its hilly nature with many valleys.

The driest month is February while July is dominantly the wettest month. Banks Peninsula shows a distinct rainfall maximum in the winter season while spring (drier regions of the study area) and summer (wetter regions of the study area) were rainfall minimums. The autumn months showed very high rainfall variability while spring showed relatively low variability.

Banks Peninsula temperature was found to be quite warmer than the surrounding plains area and with less extreme maximum and minimum temperatures. While maximum temperature showed little variation between the plains and Banks Peninsula, the minimum temperatures did. The warmer temperatures experienced on Banks Peninsula were due to being less prone to katabatic drainage of cold air from the plains and proximity to the sea. The ocean would also have a moderating influence on minimum temperatures. Summer showed the least difference in temperature variations between the surrounding plains area and the peninsula while winter showed the greatest variation. Maximum temperature was found to the least variability while minimum temperature had the greatest varability.

CHAPTER FIVE

CLIMATIC TRENDS

5.1 INTRODUCTION

In previous chapters, preprocessing of the climatic records using a homogeneity analysis techniques was described. The climatology of Banks Peninsula has also been described in terms of its rainfall and temperature patterns. In this chapter, emphasis is shifted to the description of climatic trends observed in the study area. No statistical analysis will be presented in this chapter to determine if one period of time was significantly different from another. This will be examined in the next chapter.

The major aim of climatic change study is analysis of the fluctuation and variation from "*average* " climatic values. Extensive research work has been conducted world-wide on climatic changes and fluctuations, and their impact on human activity. Studies on climatic variability have assumed more importance because of its serious impact on economic activities such as agriculture production, energy resource consumption, and disruption totransportation. Most of this work has concentrated on the northern hemisphere climate, particularly the Europe and North American regions. Recently, New Zealand climate has been studied in some detail, with emphasis on temperature and rainfall. Salinger (1975, 1979, 1980), Trenberth (1976, 1980), and Tomlinson (1980) have conducted detailed studies of New Zealand's temperature and rainfall trends since instrumental records began. The aim of this chapter is to discuss the observed climatic trends shown in the study area.

Following a literature review, an outline will be given of previous work done in New Zealand on climatic trends of rainfall and temperature. Methods used to display the climatic record of the study area will be discussed followed by a description of observed climatic trends. Historical documentary data will also be used to help validate some of the results.

5.2 PREVIOUS WORK IN NEW ZEALAND

It has only been recently that New Zealand's climatic trends have been studied in some detail. Work by Salinger and Gunn (1975) indicated that fluctuations and trends in New Zealand's temperature are in phase through out New Zealand, even as far away as the Chatham Islands and Campbell Island. Regional responses, as examined by Salinger (1980), of climatic stations through-out New Zealand, clearly indicated that most regions of New Zealand had shown similar temperature trends since instrumental records began in the mid 1860's (Figure 5.1). Work by Trenberth (1977), Salinger (1976, 1979, 1980, 1982), and Salinger and Gunn (1975) have indicated that the stations with long records suggest a climatic amelioration since the 1850's with two distinct cold periods in the 1860's and the years around 1900. Since 1950 the New Zealand climate has been warmer by 0.6ºC (Figure 5.2). Five, 10, and 20 year moving trends were used to obtain these trends. Historical data, like newspaper, and the West Coast glacial behaviour were used to validate their results (Salinger 1980).

However, there has been some debate on the post 1950 warming trend. Hessell (1980) suggests that many stations in New Zealand, especially urban stations, have been influenced by factors like urbanisation and growth of established cities around climate stations, sheltering effects from growth of buildings and trees around climate stations, and change of recording instruments. Hessell indicates that these factors account for most of the observed

FIGURE 5.1 REGIONAL TEMPERATURE TRENDS IN NEW ZEALAND

SOURCE: SALINGER (1979)

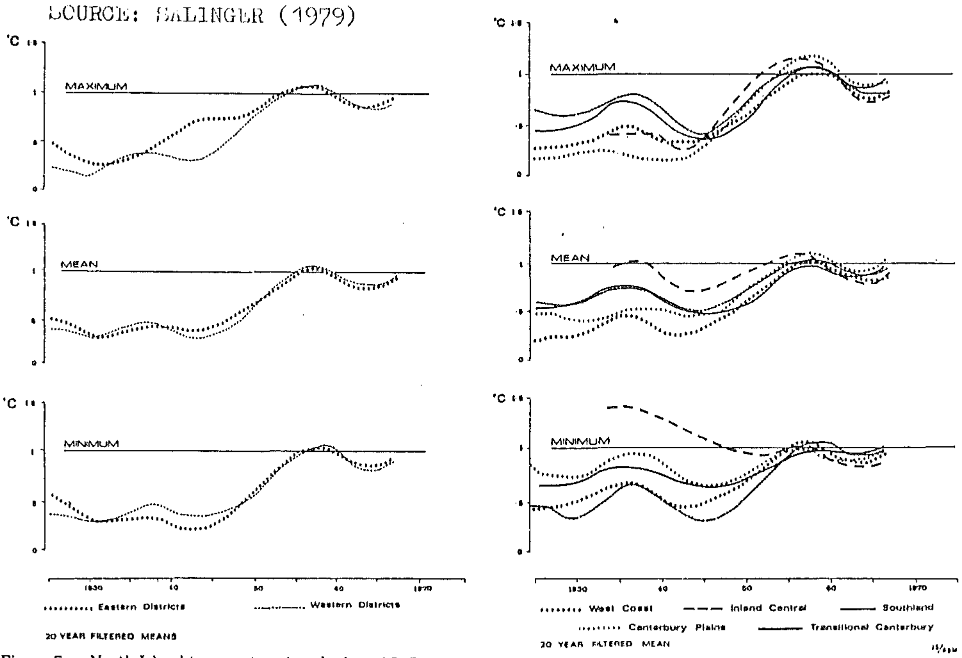


Figure 5. North Island temperature trends since 1925. The data has been smoothed by a twenty year filter.

South Island temperature trends. The data has been smoothed by a twenty year filter.

FIGURE 5.2 NEW ZEALAND TRENDS SINCE 1850

SOURCE: SALINGER (1979)

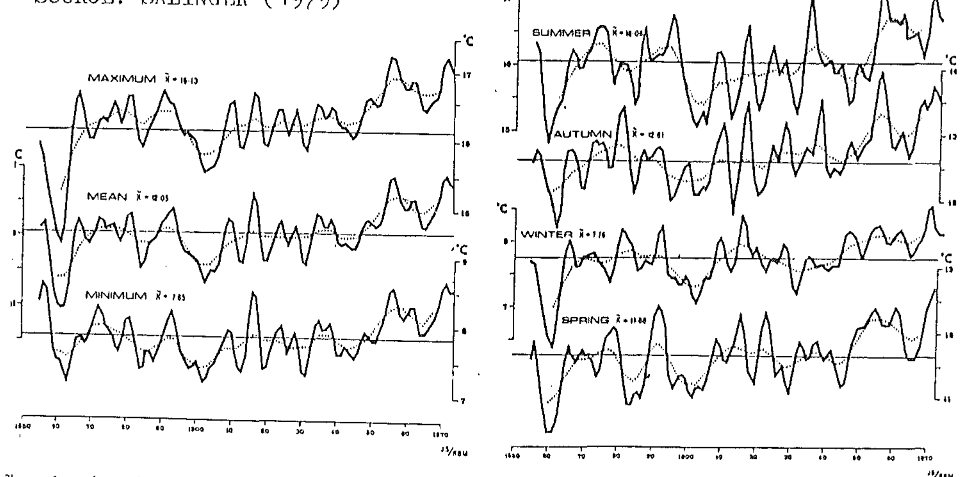


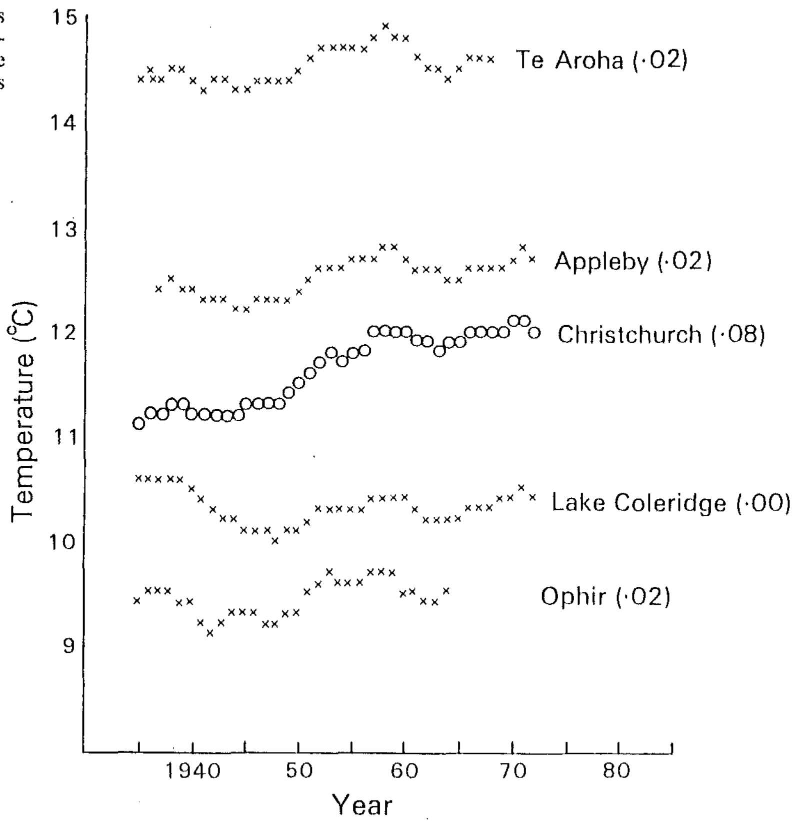
Figure 1. Annual maximum mean and minimum temperatures from composite New Zealand data. The dotted lines are filtered temperatures for 17 years, and solid lines five years.

Figure 2. Seasonal filtered temperature from composite New Zealand data. The dotted lines are filtered temperatures for 17 years and solid lines five years.

FIGURE 5.3 HESSELL'S COMPARISON OF CHRISTCHURCH MEAN TEMPERATURE TO RURAL MEAN TEMPERATURES

Hessell: Mean temperature since 1930

Fig.4 Rural mean temperatures compared with Christchurch (ten-year averages). (The numbers are linear regression slope coefficients 1935–65.)



SOURCE: HESSELL (1980)

climatic warming since 1945 and compared rural sites not affected by these factors to prove his argument (Figure 5.3).

Trends in precipitation have also been examined. Many of the previous studies have compared New Zealand rainfall trends to the 11 year sunspot cycle (Seelye 1950, Tomlinson 1980, Vines and Tomlinson 1980). Seelye indicated wet years in 1853, 1861, 1893, and 1938 with rainfall totals being over 20% above normal. Dry years with less than 85% of normal rainfall occurred in 1855, 1859, 1881, 1885, 1914, and 1930. Seelye compared sunspot activity to rainfall trends (Figure 5.4) indicating a 11 year cycle with wetter years coinciding with the sunspot maximum and drier years with minimum sunspot activity. Seelye showed that New Zealand rainfall had been in decline since 1890 with some fluctuations until 1940 when an increase in rainfall occurred (Figure 5.5). Tomlinson's (1980) study using spectral and filtering analysis indicated that a small amplitude of 10 to 11 year rainfall oscillation does exist and it is almost in phase with the sunspot cycle. He indicated that the amplitude of the rainfall oscillation corresponded to about +/- 5% of the average annual rainfall. Tomlinson (1980) work provided statistical evidence of a solar influence on New Zealand and used filter analysis to predict future trends in New Zealand. These predictions indicated very dry conditions in the mid 1980's and a return to wetter conditions

FIGURE 5.4 SEEYLE'S COMPARISON OF THE SUNSPOT CYCLE TO RAINFALL TRENDS

TABLE IV. AVERAGE RAINFALL OVER AN 11-YEAR SUNSPOT CYCLE

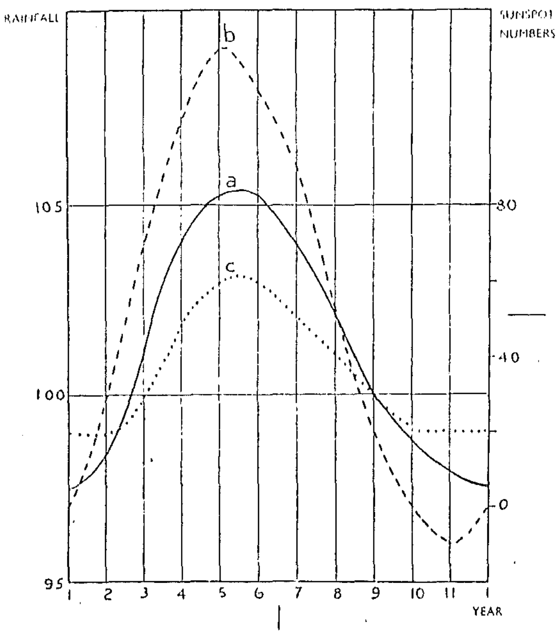


Fig. 3. Average 11-year Sunspot Cycle. (a) Sunspot numbers; smoothed rainfall for (b) North Island and (c) South Island.

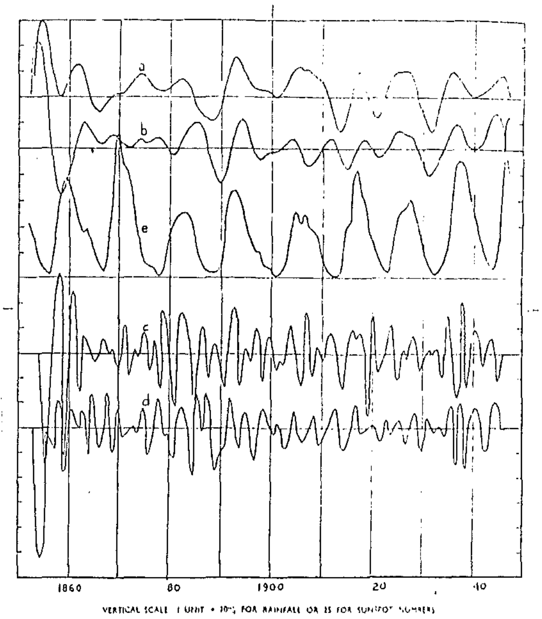


Fig. 2. Fluctuations of Annual Rainfall resolved into (a, b) longer and (c, d) shorter period components for the North and South Islands and (e) annual sunspot numbers.

SOURCE: SEELYE(1950)

FIGURE 5.5 SEEYLE'S RAINFALL TREND FOR NEW ZEALAND : 1880 - 1947

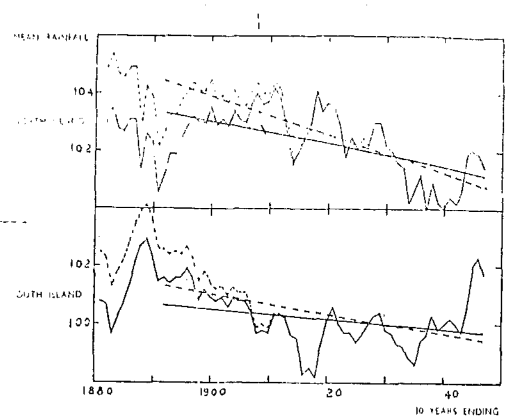


Fig. 4. Running 30-year means for (a) North Island and (b) South Island linear trends. Dotted portions show results of revising indices for years prior to 1890.

SOURCE: SEELYE (1950)

around 1990 (Figure 5.6). Drought conditions occurred in New Zealand in the 1981-1983 period.

5.3 FACTORS AFFECTING OBSERVED CLIMATIC TRENDS

In New Zealand many of the stations with long records are likely to be in the older cities and towns. The climatic station at Christchurch Botanical Gardens is one example. These urban centres have developed and grown, usually around the observation sites, modifying the micro-climate in and around the stations. Many of the urban stations are located in botanical gardens where trees have grown up providing a sheltering effect for the observation site therefore modifying its microclimate.

Sheltering effects by the growth of trees and buildings, and heat and radiational emissions from urban centres, are likely to modify the microclimates of many climatic stations. In terms of temperature, it is likely to increase the stations temperature which would subsequently show up in temperature trends (Hessell 1980). The Christchurch station is likely to show this effect. Lincoln and Onawe are essentially rural so are unlikely to be affected by urban factors although sheltering by trees could be important. It is not

FIGURE 5.6 NEW ZEALAND'S RAINFALL SERIES BY TOMLINSON USING FILTER ANALYSIS

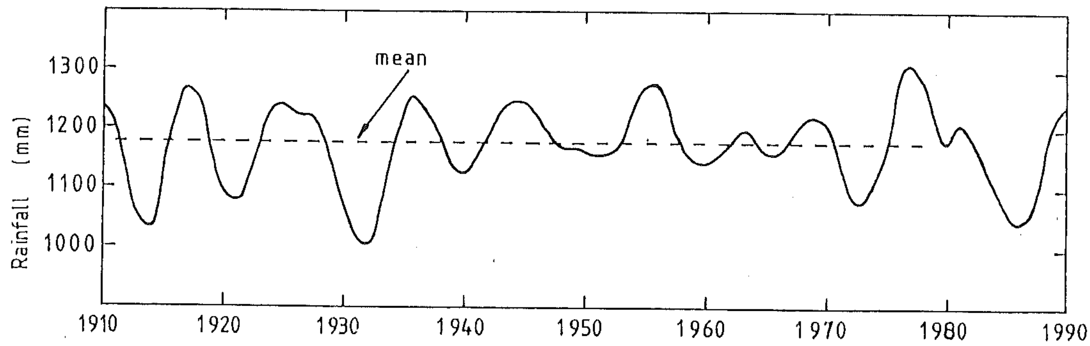


Fig. 6. The sum of the outputs of filters 1 to 4 applied to the New Zealand rainfall series. From 1969 to 1990 the graph was derived by extrapolating the graphs in Figure 5 and summing the result.

SOURCE: TOMLINSON (1980)

FIGURE 5.7 SITE CHANGES AT CHRISTCHURCH BOTANTICAL GARDEN STATION

Christchurch Botanical Gardens 1858-1982 Lat 43.5 S Long 172.6 E

Location	Height (m)	Grid Refs. NZMS 1/260	Dates of Record	Remarks
Heathcote Valley	21		Jan 1858- Dec 1861	
Provincial Bldgs.	6	S84 002562 M35 803418	Dec 1863- Apr 1876	Site shifted within buildings precint Oct 1864
Hagley Park	6	S84 995565 M35 797421	May 1876- Jan 1881	Located between a footbridge and a plantatior
Botanic Gardens	6		May 1881- Jan 1902	No readings Jul 1883-Apr 1984 Observations ceased Jul 1905
Botanical Gardens	6	S84 990563 M35 792419	Feb 1902-	Minor site shifts to improve exposure Jul 1927 & May 1950

SOURCE: THOMPSON (1984)

known to the author's knowledge at this time what effect the above factors have had on precipitation and temperature recorded in this study area.

In this thesis, changes of recording instruments, the quality of observations, and site changes are likely to affect observed climatic rainfall and temperature trends. Most stations are operated by farming families with successive generations continually recording the rainfall, therefore site changes are likely to be few. Only Lincoln and Christchurch sites have had more than one site change as far as the author knows (Figure 5.7). The quality of observations is likely to be fairly high at stations operated by farmers, as past experience and knowledge would be handed down to the younger generation. However faulty techniques will also be past down. Most stations had missing data but they were not extensive at any one station. Homogeneity assessment and preprocessing of climatic records was done to improve the records as explained in Chapter 3.

5.4 METHODS

Rainfall and temperature moving averages were used to determine the climatic trends observed in the record. Ten and thirty year moving averages were used. The 10 year moving trends were used

TABLE 5.1 EXAMPLE OF HOW CATEGORIES WERE DETERMINED

STATION : Christchurch

TREND : 10 year moving trends

PERIOD : Annual trends

YEAR	RAINFALL (mm)	YEAR	TEMPERATURE (ºC) max	min	mean
1867	721	1914	16.0	6.2	11.1
1868	710	1915	16.2	6.2	11.2
...	...	...	...	...	...
...	...	...	...	...	...
1984	731	1984	17.0	7.0	12.5
1985	700	1985	17.0	7.2	12.6
MEAN	658		16.4	6.8	11.6
S.D.	48		0.5	0.2	0.4

CATEGORTIES OF SPELLS BASED ON STANDARD DEVIATIONS (S.D.)

RAINFALL PERIODS

Extremely Dry		Very Dry		Dry		Normal		Wet		Very Wet		Extremely Wet
<——————>	3	<——————>	2	<——————>	1	<——————>	1	<——————>	2	<——————>	3	<——————>
	(514)		(562)		(610)		(706)		(754)		(802)	

TEMPERATURE PERIODS

	Extremely Below Normal		Well Below Normal		Below Normal		Normal		Below Normal		Well Below Normal		Extremely Below Normal
	<——————>	3	<——————>	2	<——————>	1	<——————>	1	<——————>	2	<——————>	3	<——————>
Mean Temp		(10.4)		(10.8)		(11.2)		(12.0)		(12.4)		(12.8)	

to determine short term climatic events and comparison of one decade to another. Thirty year moving trends were used to determine longer term trends. The New Zealand Meteorological Service also uses 30 years to determine average climatic values for its stations. As previously stated, eight stations from each region were used to represent the rainfall trends in the study area while six stations with temperature records longer than 10 years were used.

Monthly, seasonal, and annuals trends were graphed. Horizontal bar graphs were used to illustrate periods of normal, and above and below normal rainfall and temperature. This was determined by calculating the standard deviation (S.D.) of the moving trends (Table 5.1). The following 2 examples shows how the rainfall and temperature trends were categorised into specific periods:

1) Mean Rainfall +/- S.D. = Normal Rainfall

2) Mean Temperature -(2*S.D.) ≤ Below Normal Temperature ≤ Mean Temperature - S.D.

5.5 OBSERVED CLIMATIC TRENDS OVER THE STUDY AREA

5.5.1 RAINFALL

5.5.1.1 Climatic Record

Christchurch Botanical Gardens and Akaroa stations are used to show the recorded history of rainfall in the study area.

Figure 5.8 shows the annual and seasonal rainfall of Christchurch and Akaroa while Figure 5.9 shows the driest (February) and wettest (July) months of the year. Possible wet and dry periods can be determined like the grouping of dry years in the 1930's and wet years in the 1974-1980 period.

5.5.1.2 Ten Year Trends

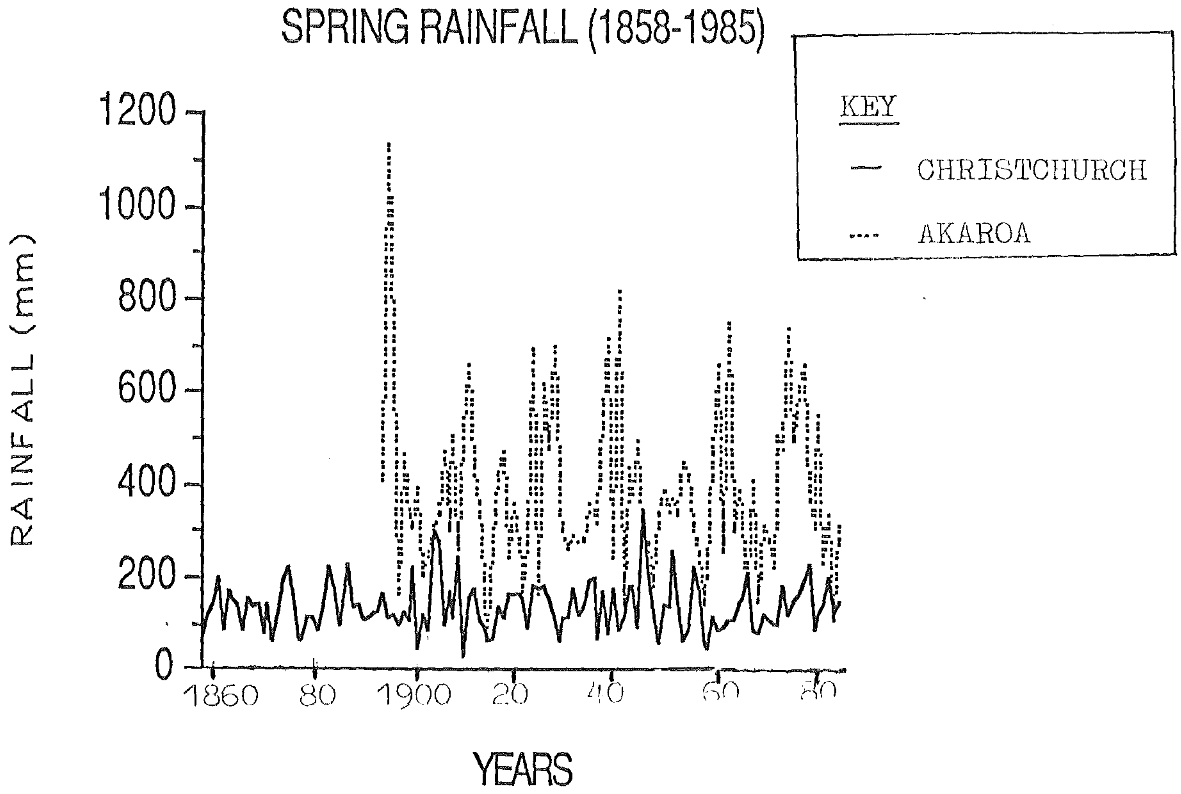
For 10 year and 30 year moving rainfall trends February, July, seasonal, and annual trends will be shown in this chapter.

Figure 5.10 and Figure 5.11 show the rainfall trends of the eight representative stations in line graph form. The graphs indicate that the stations with high rainfall totals, like Okuti and Akaroa, fluctuate much more widely in comparison to stations with low rainfall totals like Christchurch and Lincoln. This indicates a higher variability of rainfall in the wetter regions compared to the drier regions of the study area. Two possible reasons could account for this:

1) During dry periods, from monthly to annual scale, rainfall distribution over the study area is relatively similar.

2) During wet periods, from a monthly to annual scale, rainfall totals are much higher in the wetter regions than in the drier regions

FIGURE 5.8 ANNUAL AND SEASONAL RAINFALL TOTALS AT CHRISTCHURCH AND AKAROA SINCE RECORDS BEGAN



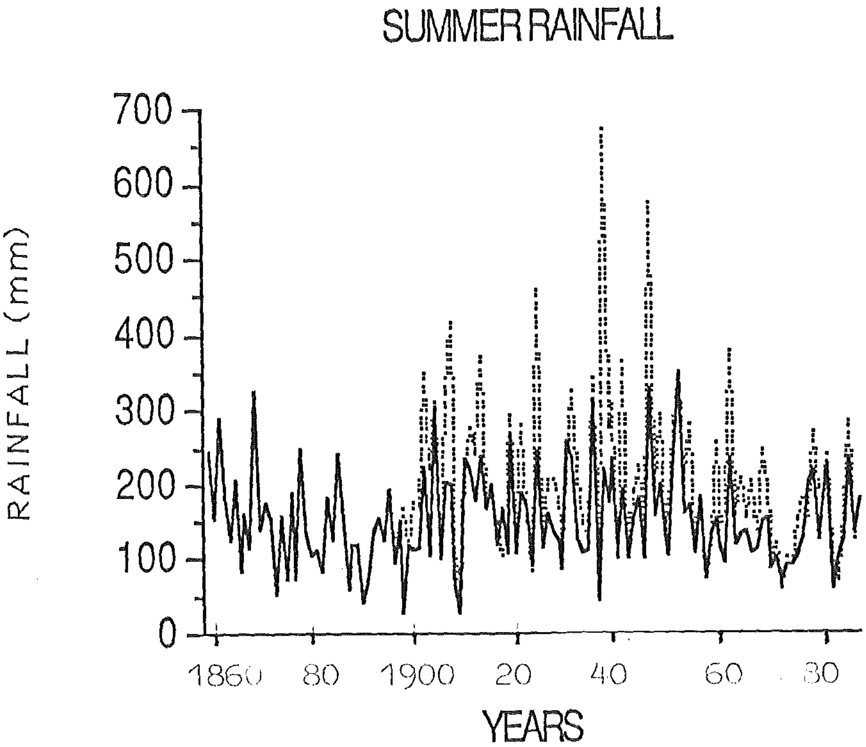
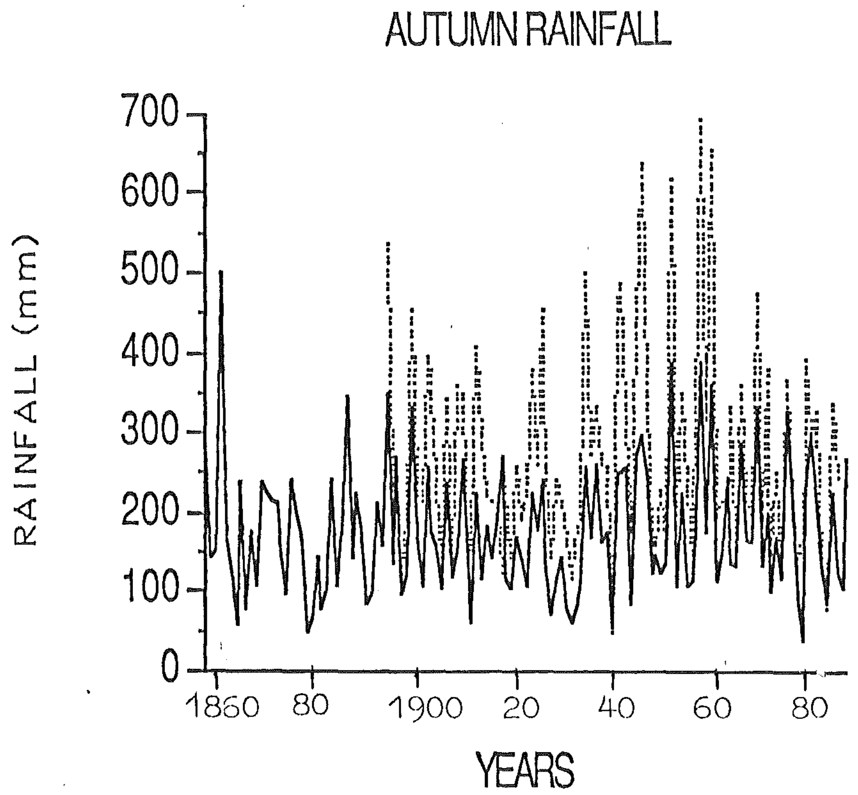


Figure 5.8 continue



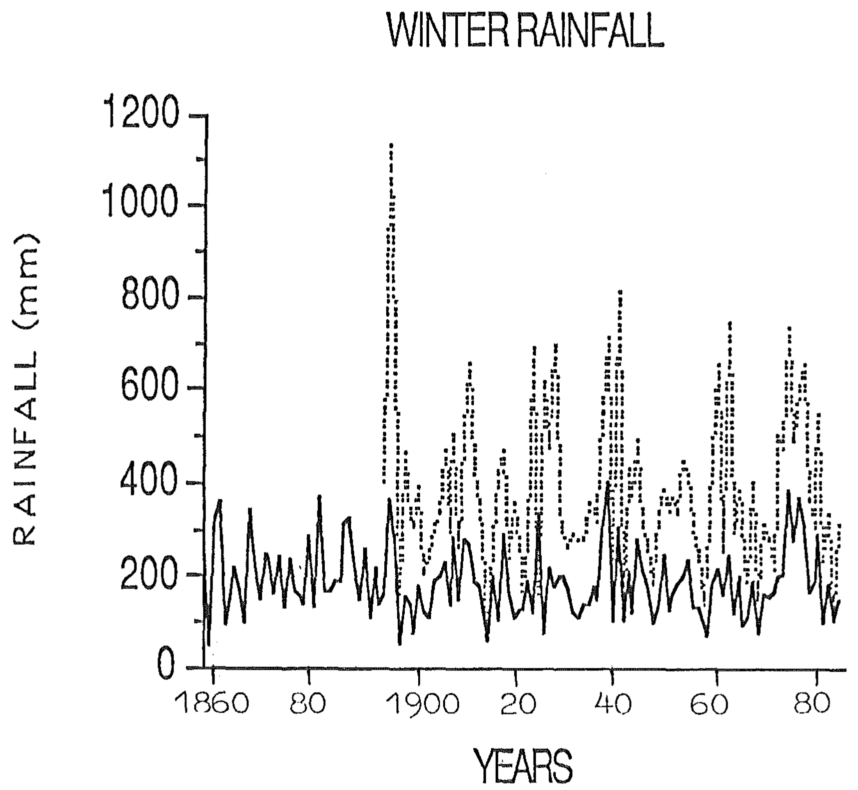


Figure 5.8 continue

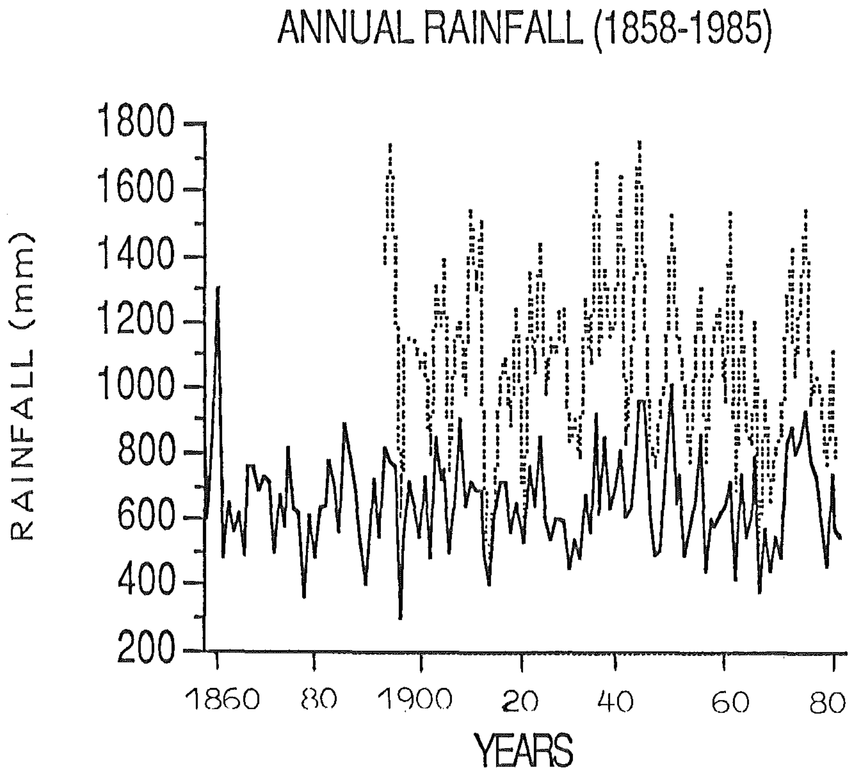
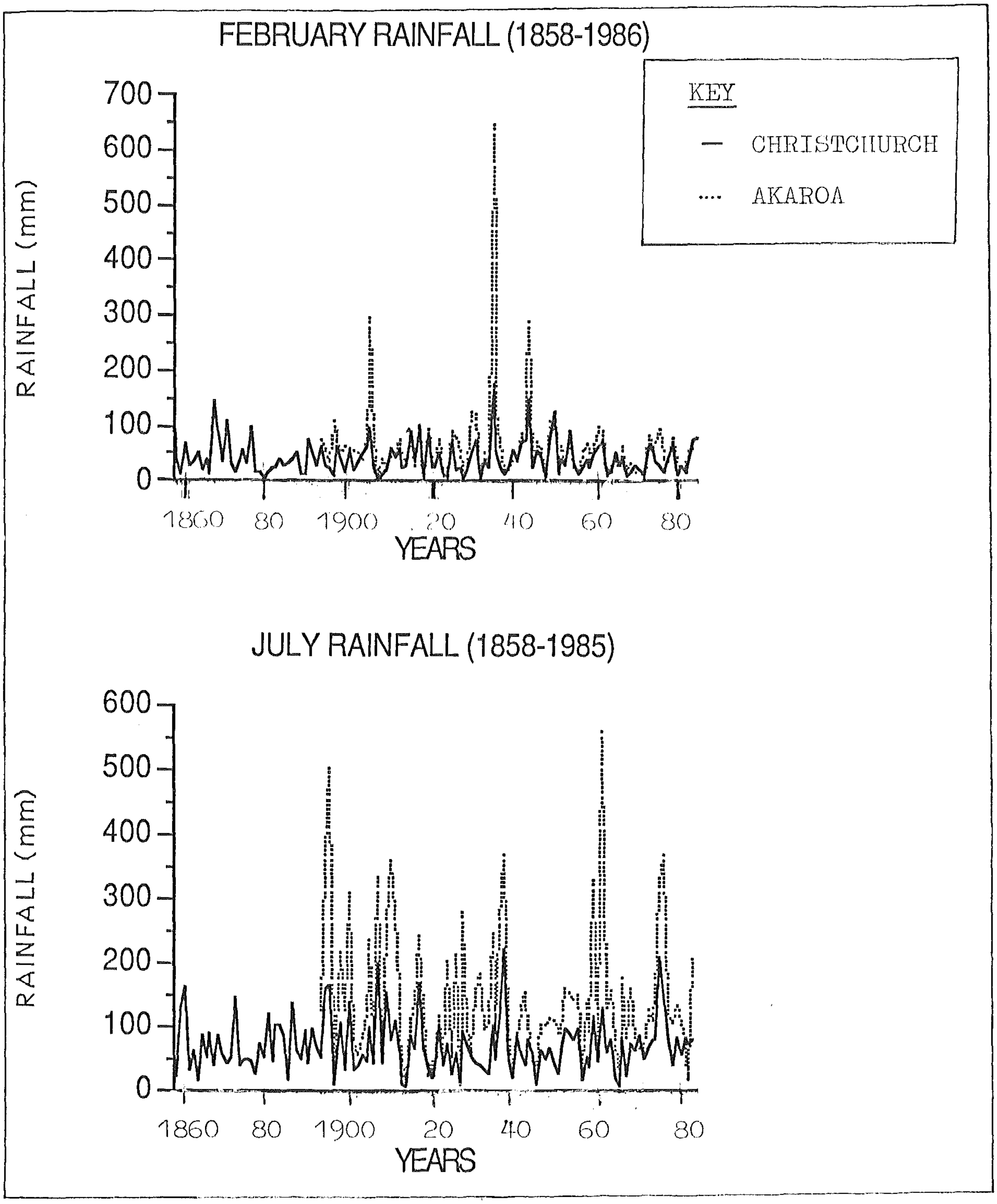


FIGURE 5.9 THE CLIMATIC RECORD OF THE DRIEST AND WETTEST MONTHS AT CHRISTCHURCH AND AKAROA



of the study area.

The rainfall graphs in chapter 4 (Figure 4.2) showing maximum and minimum rainfall totals recorded at eight sites supports this view of higher rainfall variability in the wetter regions of the study area.

Figure 5.12 and Figure 5.13 shows the wet, normal, and dry spells that have occurred over the study area using 10 year moving trends. The eight stations tend to indicate that wet, normal, and dry spells occur simultaneously over the study area, but local variations do occur. This generally indicates that one region of the study area does not experience a very dry spell while another region experiences a very wet spell. Extreme dry and wet spells do not occur often and are usually of short duration.

In the next section seasonal trends and some of the more interesting months will be discussed.

Seasonal trends

The 1870's to early 1900's were consistently dry periods, but varying in length between the four seasons. Summer and spring were the most affected seasons (Figure 5.10). During the 1890's the summer rainfall totals at Christchurch and Lincoln dropped below 125mm during the peak of the dry spell. The summer dry spell of the late 1960's to 1974 was probably drier than the 1890's but didn't last as long. At Lincoln and Christchurch, January and February average 10

FIGURE 5.10 TEN YEAR MOVING TRENDS FOR SEASONAL AND ANNUAL RAINFALL OF THE EIGHT REPRESENTATIVE STATIONS

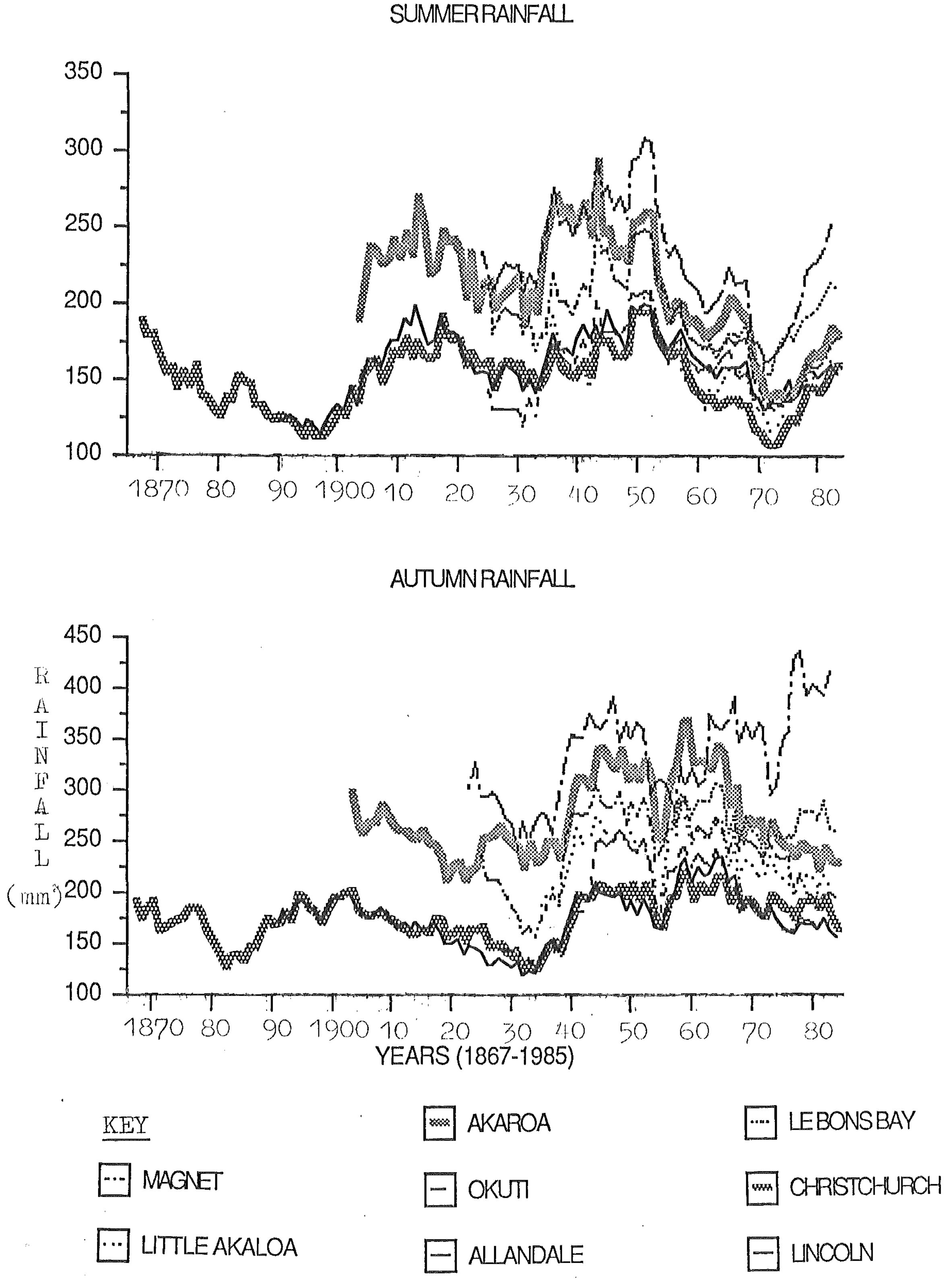
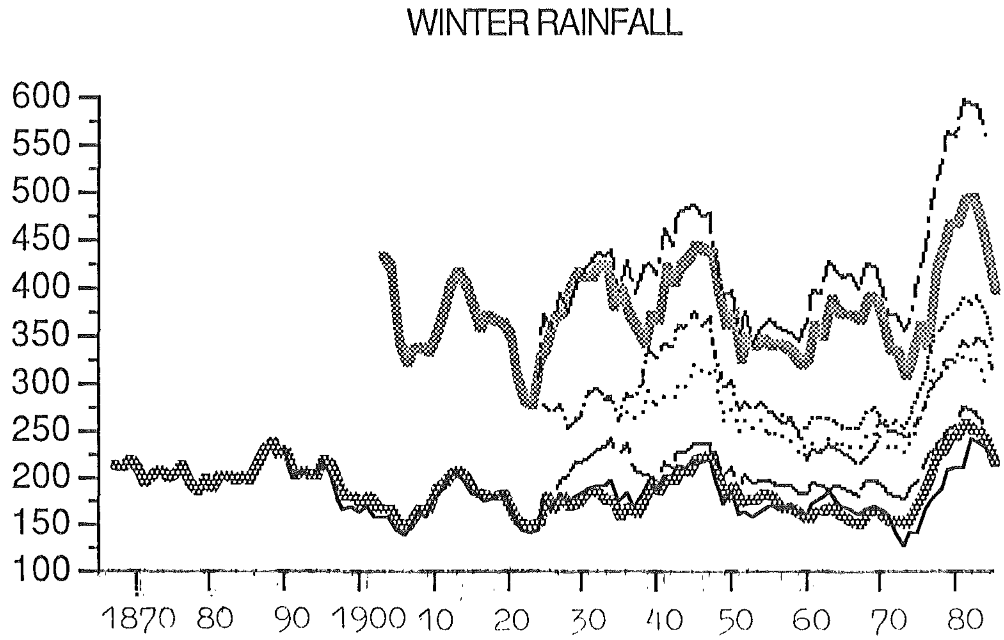


Figure 5.10 continue



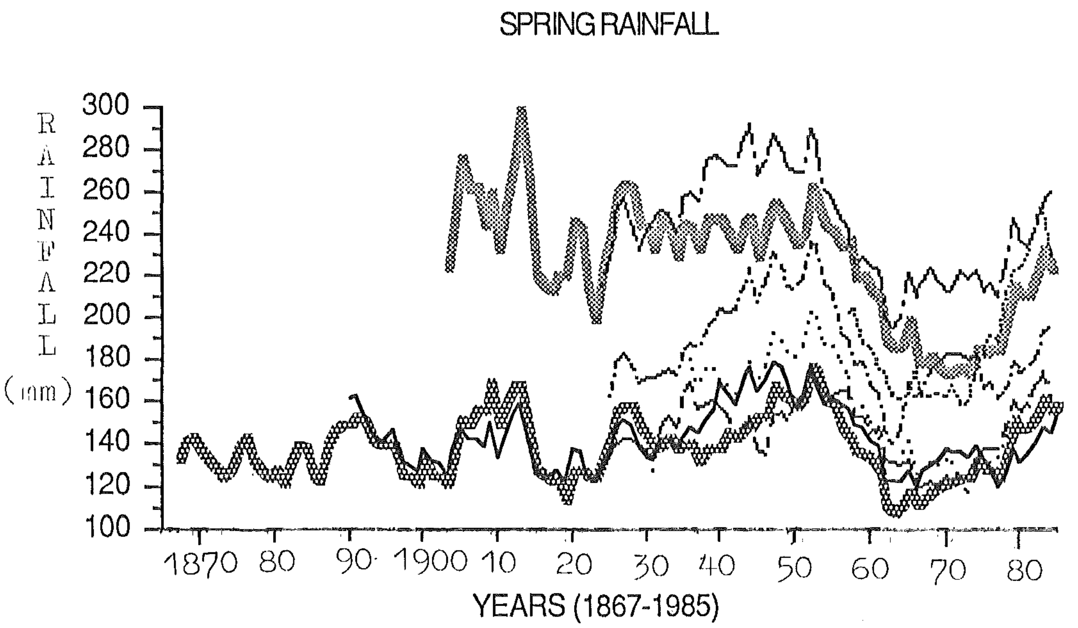


Figure 5.10 continue

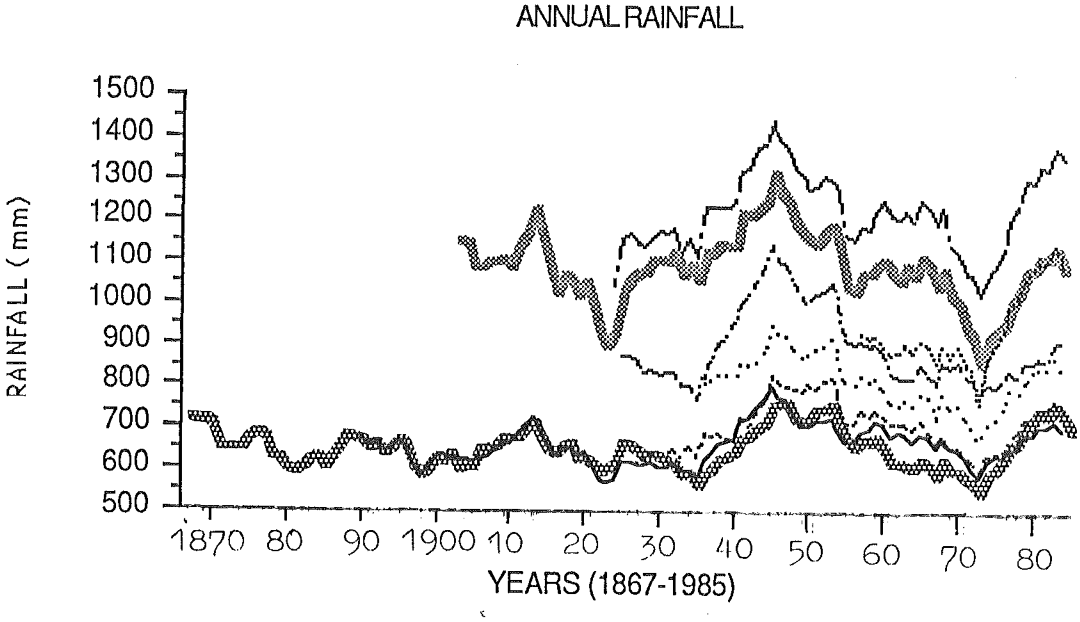
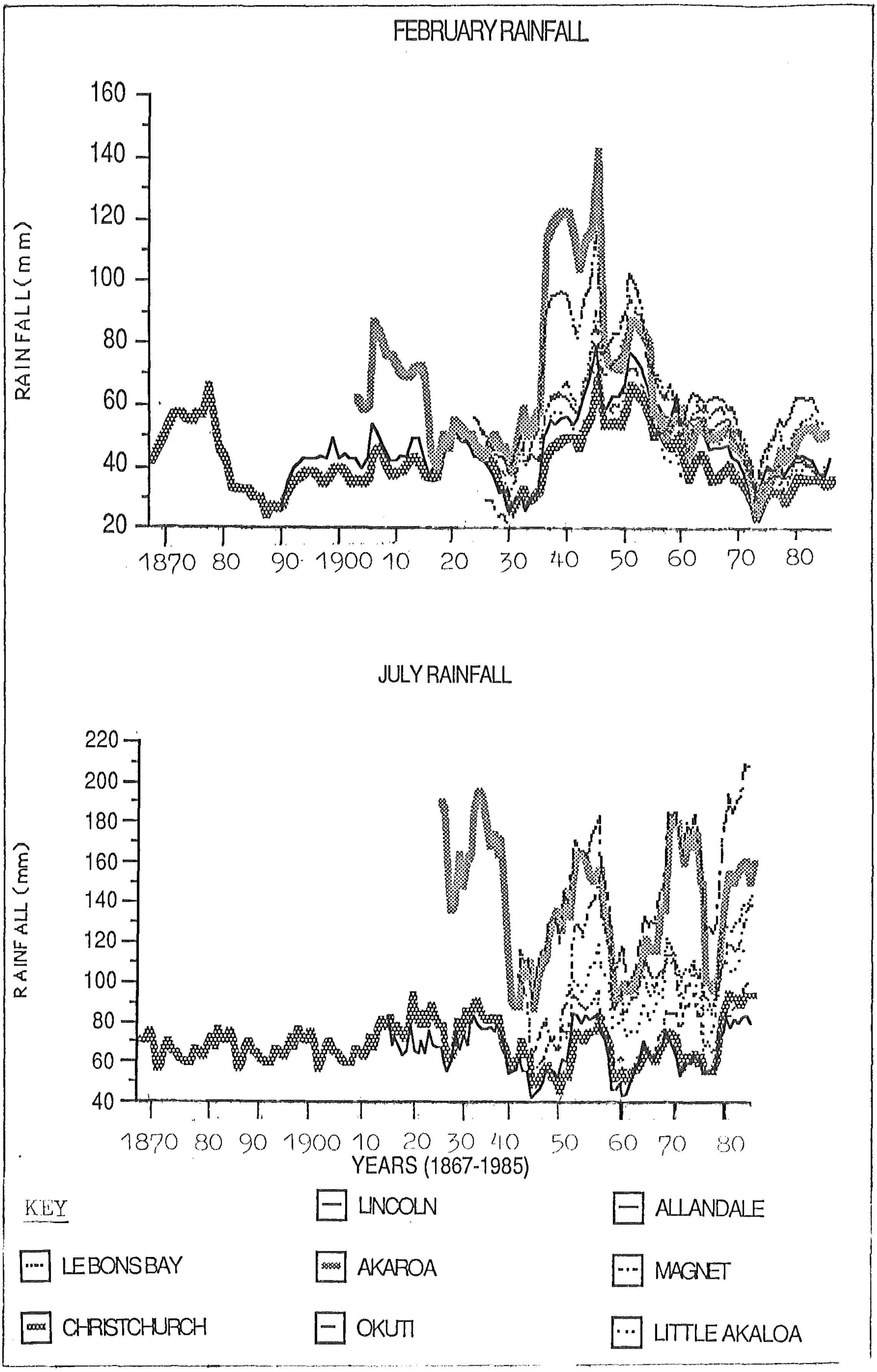


FIGURE 5.11 TEN YEAR MOVING TRENDS FOR THE DRIEST (FEBRUARY) AND WETTEST (JULY) MONTHS OF THE YEAR



year rainfall totals occasionally got below 40mm during both of these dry spells. The dry spell of the 1890's was most pronounced in January, lasting approximately from 1890 to 1910. However, during the 1970's dry spell it was most pronounced in December and non existence in January. Autumn only had a dry spell in the 1880's. Winter had no dry periods during the 1870's to 1900 but instead recorded a small wet spell in the 1890's. However winter dry periods occur in the 1900's. The month of August had an extensive dry spell from the early 1900's to 1925 which lasted longer on the plains than on Banks Peninsula. In Christchurch this dry spell lasted for 27 years.

The years around 1910 were a wet period for spring while the late 1910's was a wet period for summer.

The 1920's to 1930's saw a return to dry conditions especially for autumn. Both the 1880's and 1930's autumn dry spell saw Christchurch average 10 year rainfall total drop below 150mm. An extensive dry spell occurred in March from 1920 to 1935 with Christchurch having an average rainfall of 33mm, Lincoln 35mm, and Magnet Bay 31mm. This dry spell was more extensive on the plains area than on Banks Peninsula. Summer was the only season during the 1920-30's that didn't experience a dry spell.

The 1940's-50's saw a return to wet conditions This was the wettest period experienced since records began. This was probably also true for the rest of the Canterbury region. In autumn this wet period lasted 25 years from 1945 to 1970. However April had its wet spell from 1968 to approximately 1984. Akaroa averaged 110mm of rainfall during this period.

Apart from autumn the 1960's to early 1970's saw a return to dry conditions. For summer and spring this was probably their driest spells experienced since records began. However the month of June at Christchurch saw a dry spell lasting 16 years during this period.

A short but vey wet period occurred over the study area from 1974 to 1980. This was mainly due to the more frequent occurrence of moist east to northeast airstreams over New Zealand. This wet spell mainly affected the winter season resulting in sharply rising 10 year average rainfall totals in the late 1970's to 1980's. In fact the 1974 to 1981 winters may have been the wettest winter period to occur in the study area since records began.

Dry spells seem to be a feature of spring rainfall trends rather than wet spells. Four dry spells have occurred in spring while two wet spells have occurred. This may be the result of the strengthening westerlies during this period.

In the summer season there is a possibility of cyclic trends occurring (Figure 5.10). It may be possible that a wet spell occurs in the study area every 35 to 40 years with a dry spell occurring every

FIGURE 5.12 THE OCCURRENCE OF DRY, NORMAL, AND WET SPELLS (10 YEAR MOVING TRENDS) ON A SEASONAL AND ANNUAL BASIS

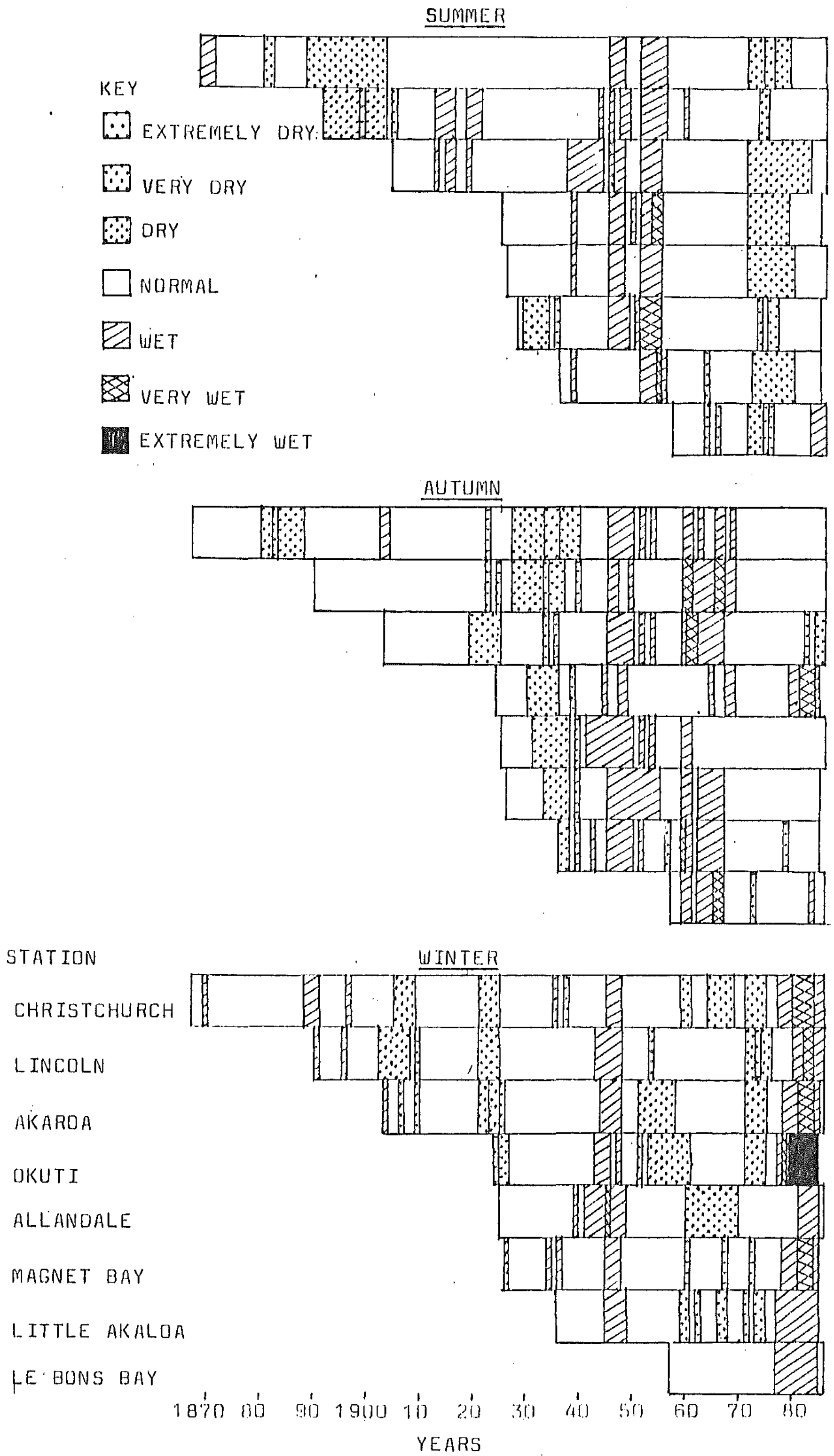


Figure 5.12 continue

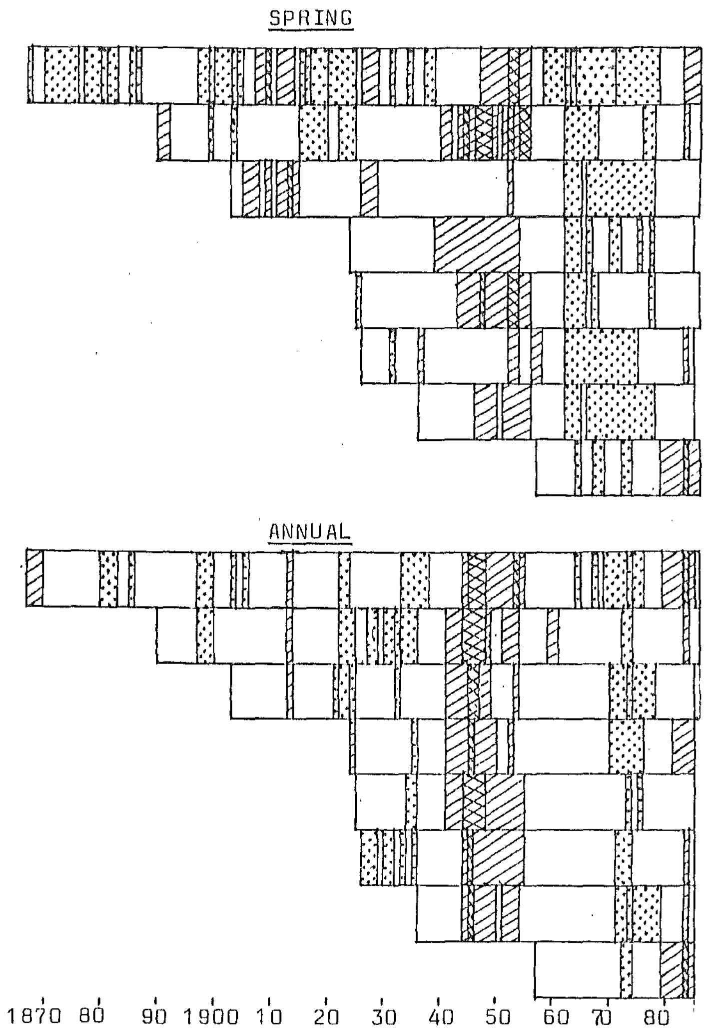
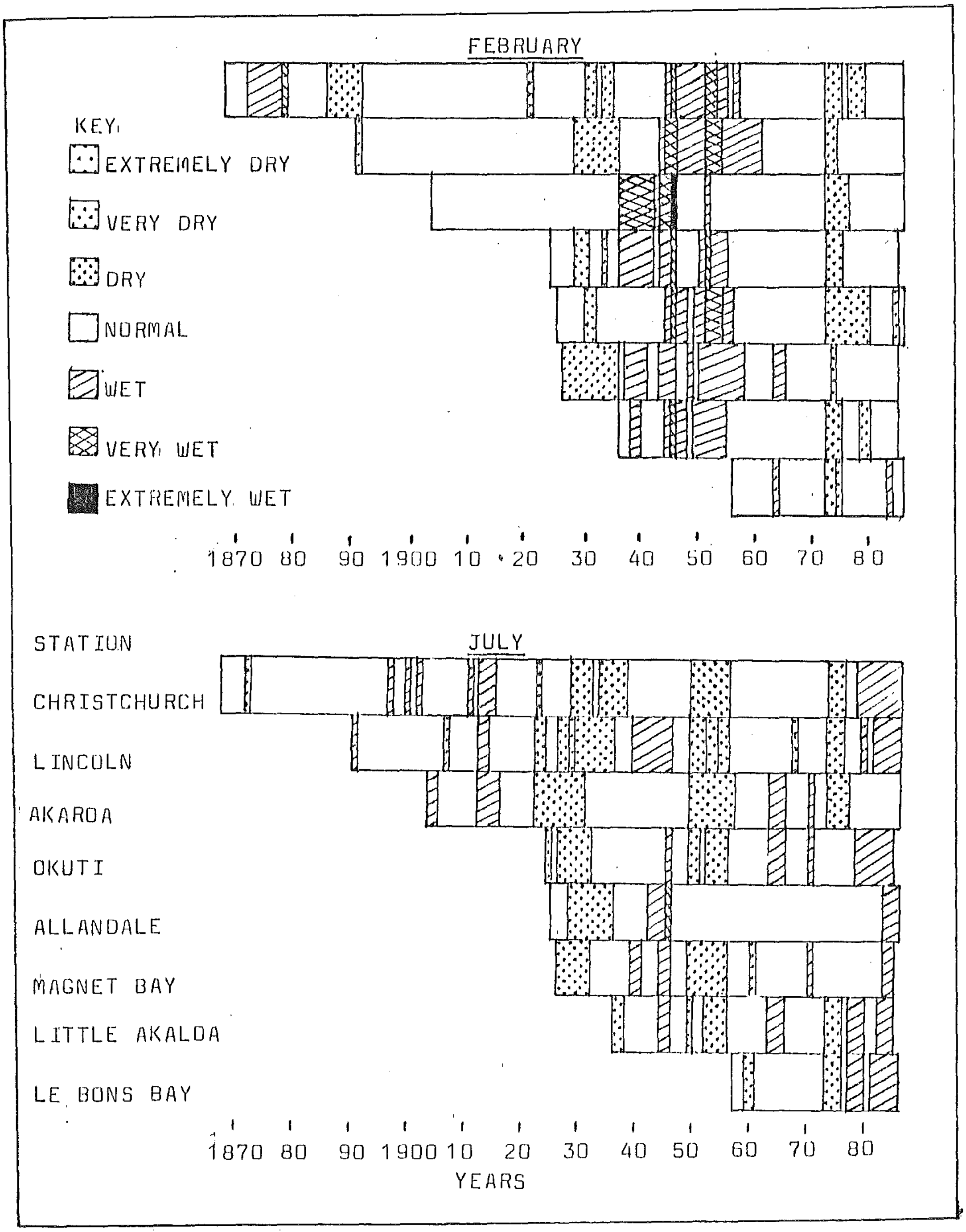


FIGURE 5.13 THE OCCURRENCE OF DRY, NORMAL, AND WET SPELLS (10 YEAR MOVING TRENDS) FOR THE DRIEST (FEBRUARY) AND WETTEST (JULY) MONTHS



80 years. This would indicate that a wet spell would begin around 1990. On a monthly basis February seems to show a 40 year dry spell cycle (late 1880's, early 1930's, 1970's), and with December showing a 40 year wet spell cycle (1860's, 1910's, 1940's-50's, mid 1980's). The line and bar graph of October rainfall trends seem to sugggest a regular cycle of wet and dry spells every 20 to 25 years.

In the future, using present trends, summer and spring may become wetter while winter and autumn become drier. However the 1986 winter was the wettest the study area has experienced since 1977. A closer examination of the line graphs suggests that sunspot activity may have a significant cyclic effect on rainfall trends, particularly the winter season.

Annual

Two main wet and dry spells have been recorded in the study area since records began. The dry spells occurred in the 1920's to 1930's and the 1970's while the wet spells occurred in the 1940's to the early 1950's and the 1980's. Christchurch rainfall trends seems to suggest a declining rainfall from 1867 t0 aprroximately 1935 with some fluctuations occurring.

5.5.1.3 Thirty Year Trends

Thirty year moving trends smooth out the extremes that 10 year trends show therefore providing a long term rainfall trend. Also

FIGURE 5.14 THIRTY YEAR MOVING TRENDS FOR THE DRIEST (FEBRUARY) AND WETTEST (JULY) MONTHS OF THE

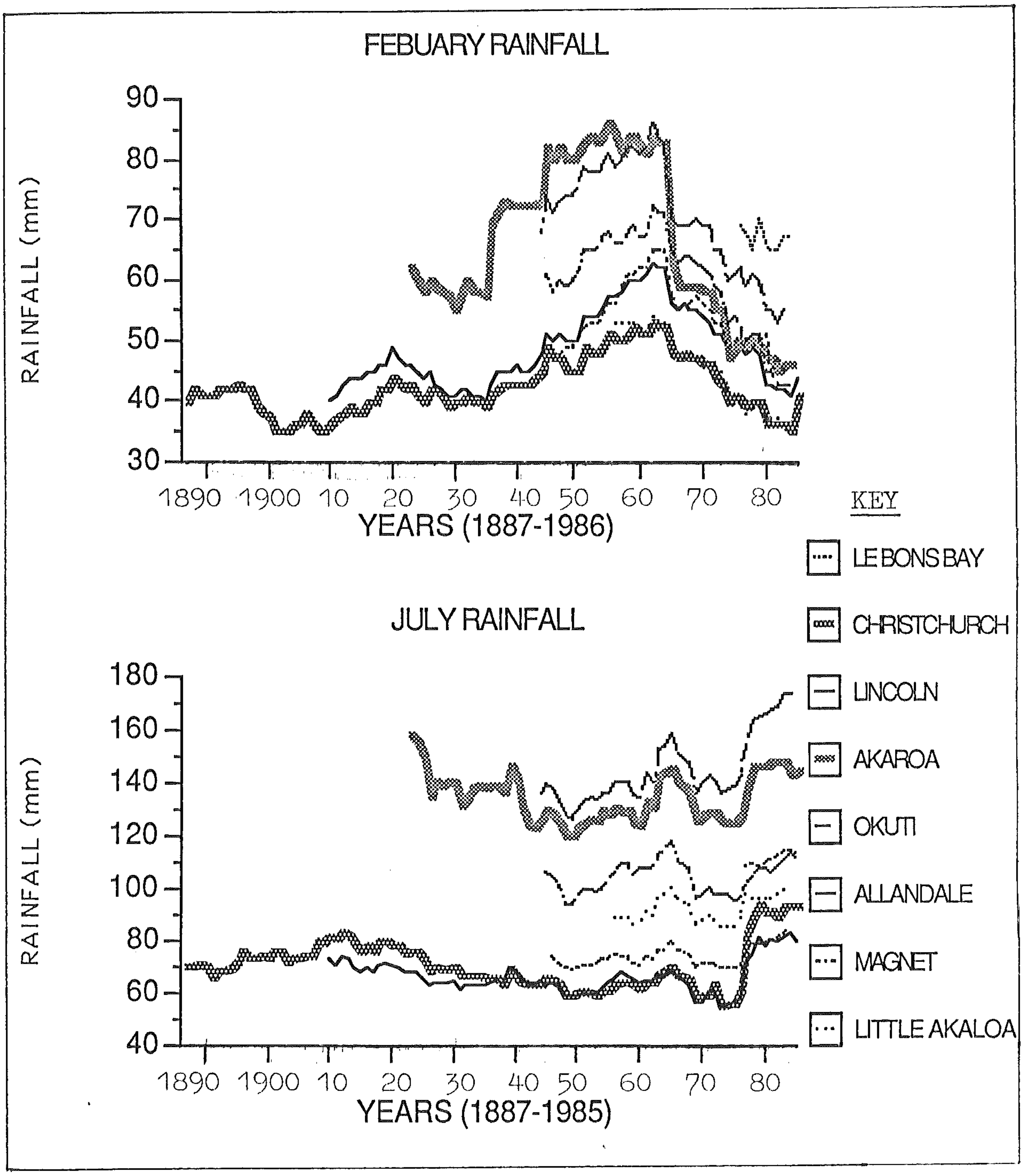


FIGURE 5.15 THIRTY YEAR MOVING TRENDS FOR SEASONAL AND ANNUAL RAINFALL AT THE EIGHT REPRESENTATIVE STATIONS

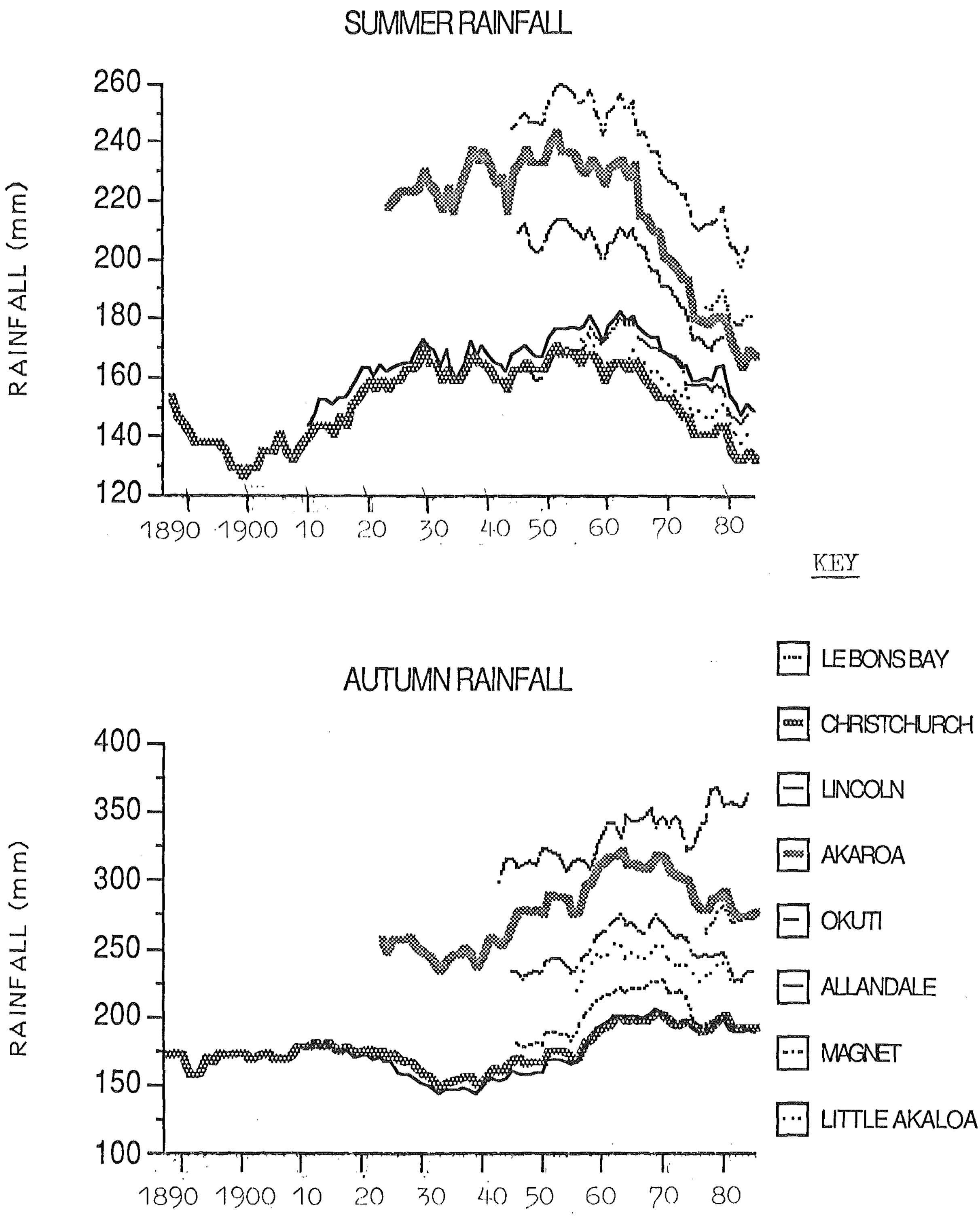
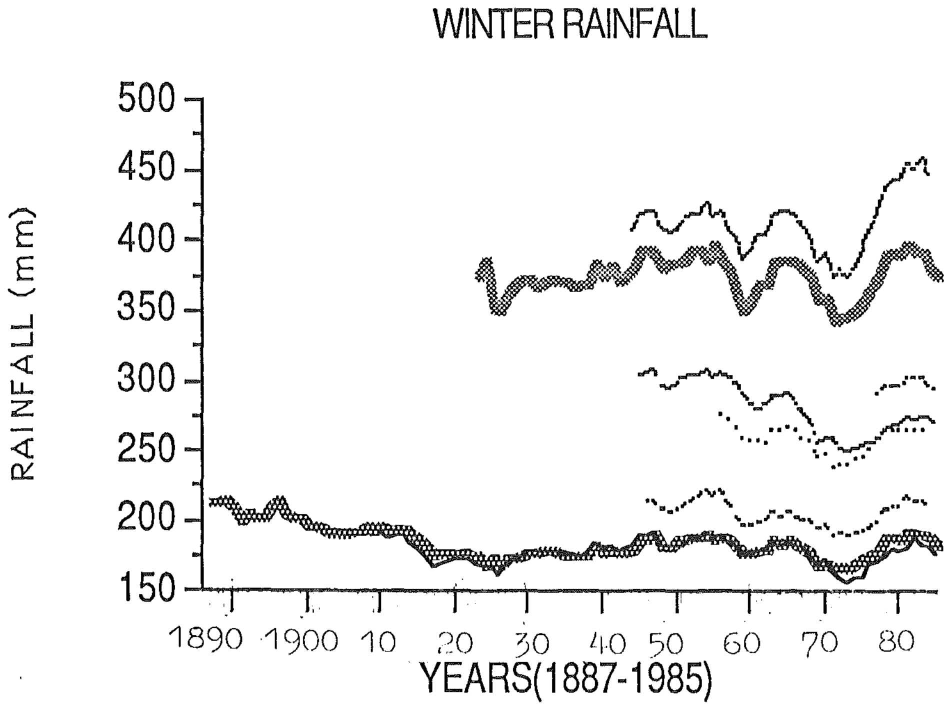


Figure 5.15 continue



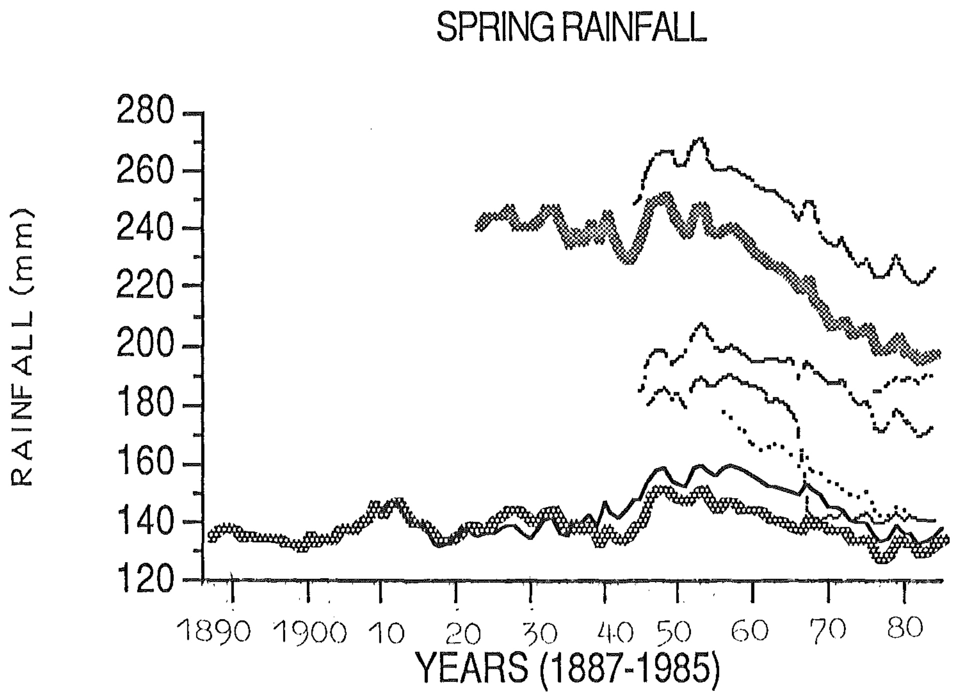
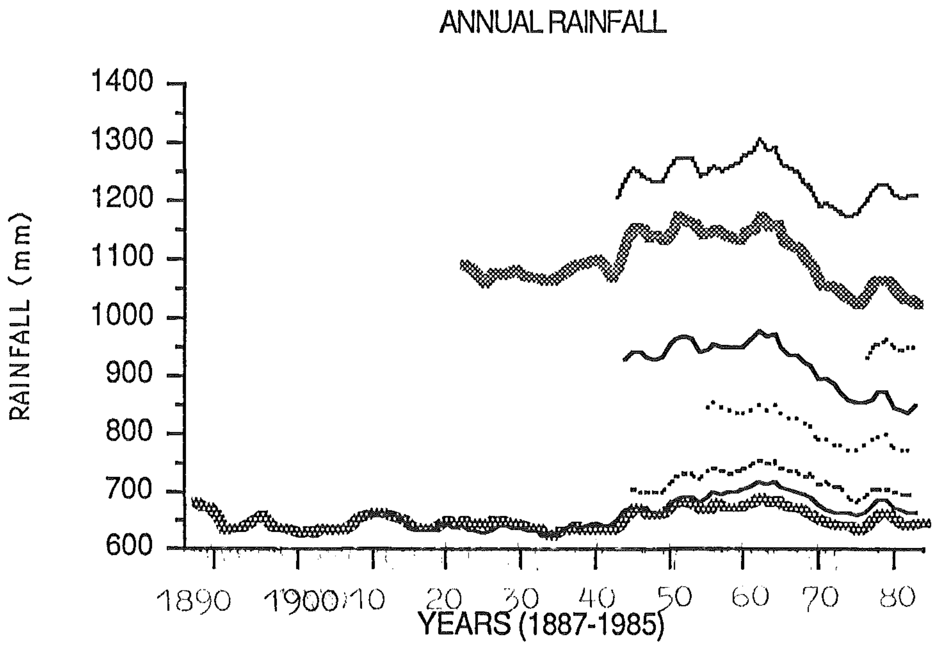


Figure 5.15 continue



year cycle with a broad crest indicating a long period of above normal summer rainfall, and a short deep trough indicating a short period of very dry summers. Spring rainfall, since the wet springs of the 1950's, has seen a progressive drying with a subsequent dry spell in the 1980's. Akaroa has seen its 30 year average autumn rainfall drop from 260mm (1950) to around 200mm (1985).

Some of the months also show intersesting trends. The March rainfall pattern suggests a regular alterating cycle of wet and dry spells. April trends show an extensive dry spell from the 1930's to 1950's and a wet spell from the 1970's to the present. The present April wet spell is the wettest on record. May rainfall shows relative stability from the 1880's to 1950's. June rainfall tends to show a progressive drying from 1887 to the present, apart from the wet spell in the 1940's to 1950's. July rainfall (Figure 5.16) also shows a drying tendancy from 1910's to late 1970's, then there has been an abrupt increase in rainfall with parts of Banks Peninsula experiencing a wet spell in the 1980's. This relates to the wet winters experienced from 1974 to 1980 which shows up on the 10 year scale. September has had a rapid decrease in average rainfall totals since 1950, especially for Okuti and Akaroa stations.

Annual trends

Figure 5.17 indicates that the study area, especially the plains the 30 year trend is less vulnerable to any one extreme rainfall event.

Figures 5.14 and 5.15 shows the February, July, seasonal, and annual trends with the bargraphs shown in Figures 5.16 and 5.17. As shown in the 10 year trends the wetter stations fluctuate much more widely than the drier stations.

Seasons

The 1880's to 1890's was a wet spell for autumn (Figure 5.16). However for summer the 1890's and 1900's was a dry spell. In the late 1910's to 1930's a dry spell occurred in the winter season. Autumn also experienced a dry spell in the 1930's. The 1920's-30's saw spasmodic wet spells in different parts of the study area. The 1930's saw the beginning of a wet summer spell which lasted until 1970. It first began on the plains then spread to Banks Peninsula. This links up with the wet summers spells experienced on the 10 year scale in the 1910's and 1940's - 50's. The 1940 to 1970 period was a wet period for all seasons except winter. In fact, winter has not experienced a wet spell in the 20th Century. The 1970's saw the beginning of a dry period which first began in winter and in the 1980's spread to summer and spring. However autumn continues to be wet in some parts of Banks Peninsula in the 1980's.

A closer examination of the line graphs shows some interesting trends. The summer line graph (Figure 5.16) seems to suggest a 90

FIGURE 5.16 THE OCCURRENCE OF DRY, NORMAL, AND WET SPELLS (30 YEAR MOVING TRENDS) FOR THE DRIEST (FEBRUARY) AND WETTEST (JULY) MONTHS

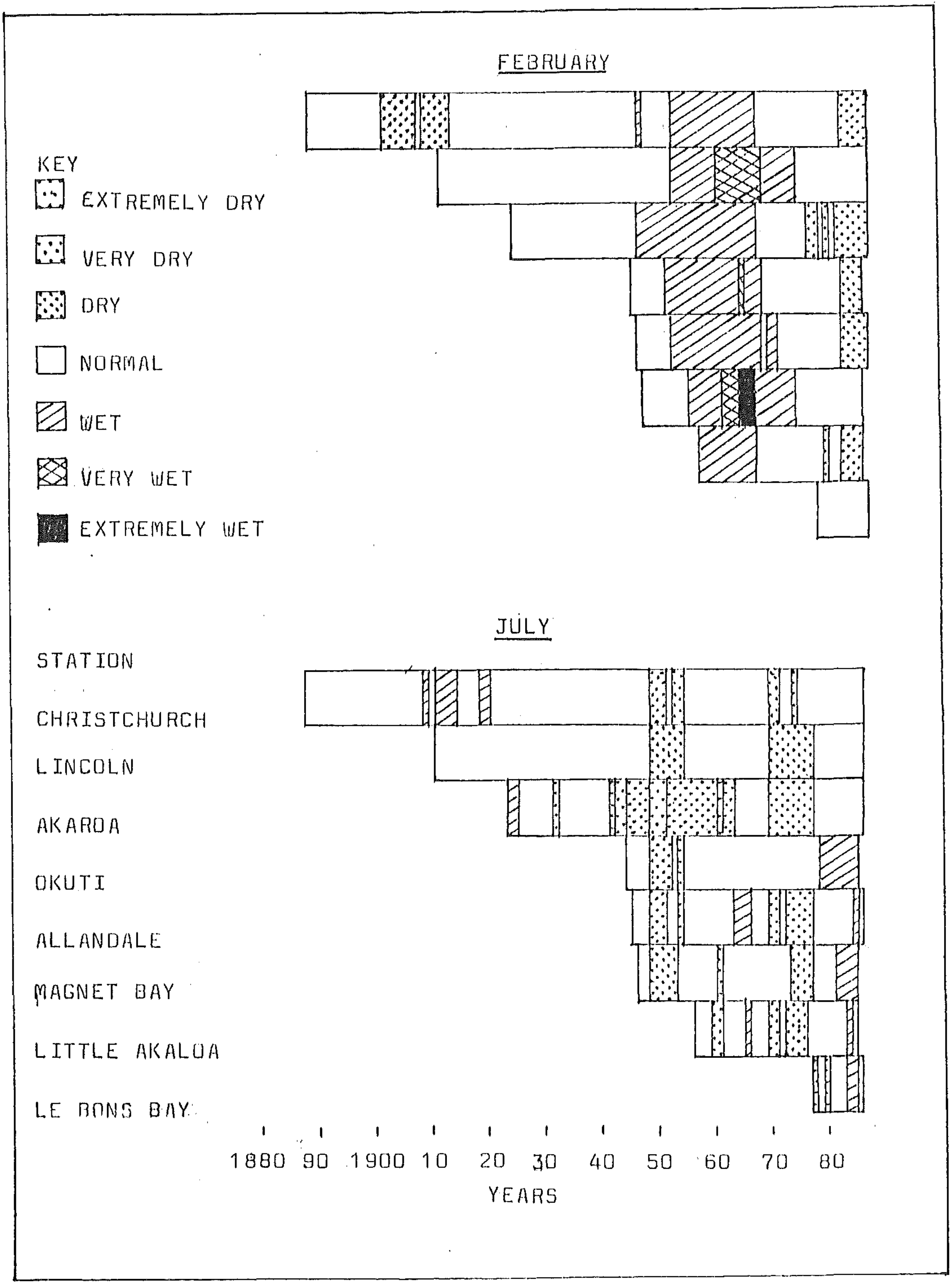


FIGURE 5.17 THE OCCURRENCE OF DRY, NORMAL, AND WET SPELLS (30 YEAR MOVING TRENDS) FOR SEASONAL AND ANNUAL TRENDS FOR THE EIGHT REPRESENTATIVE STATIONS

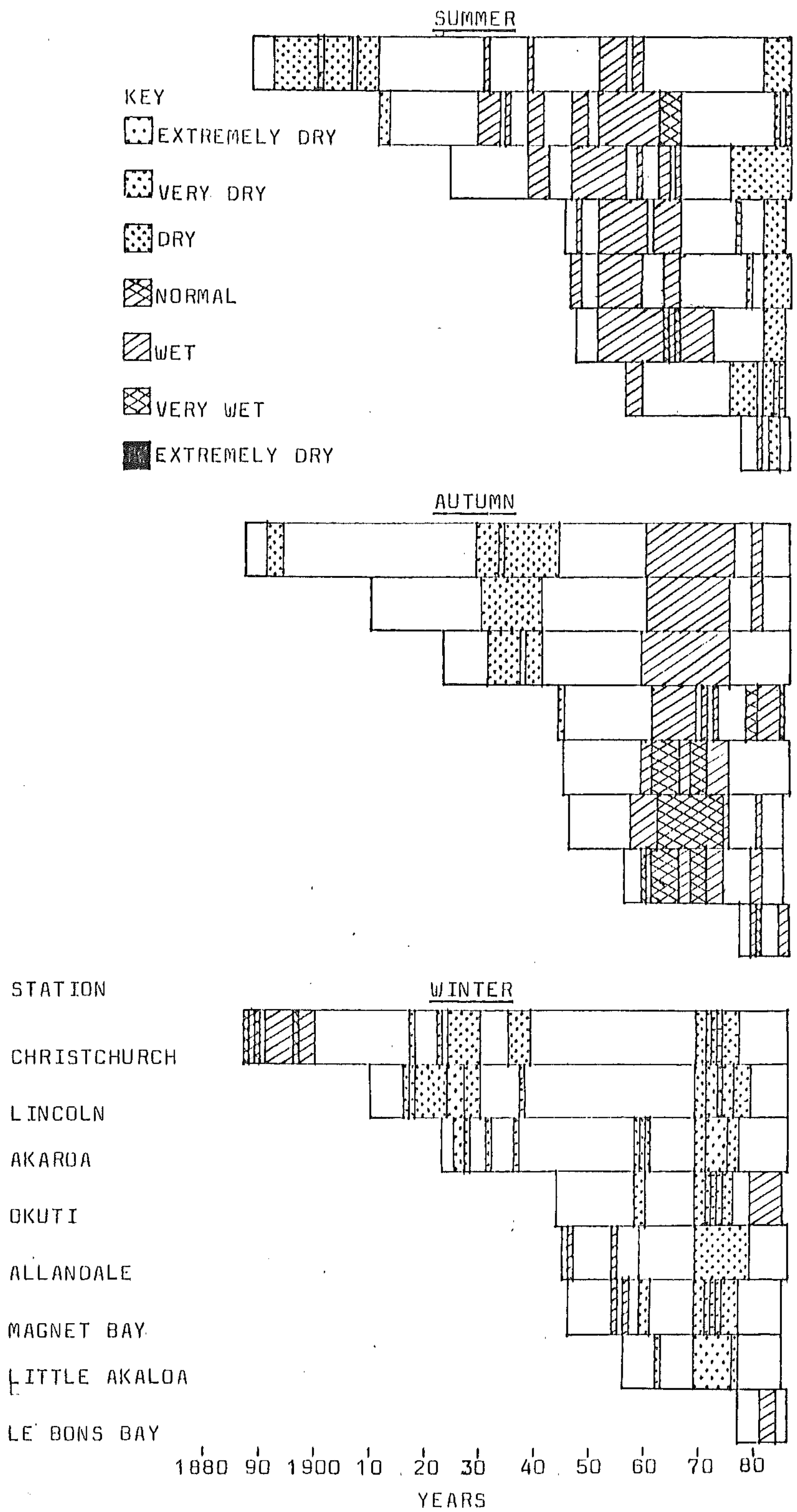
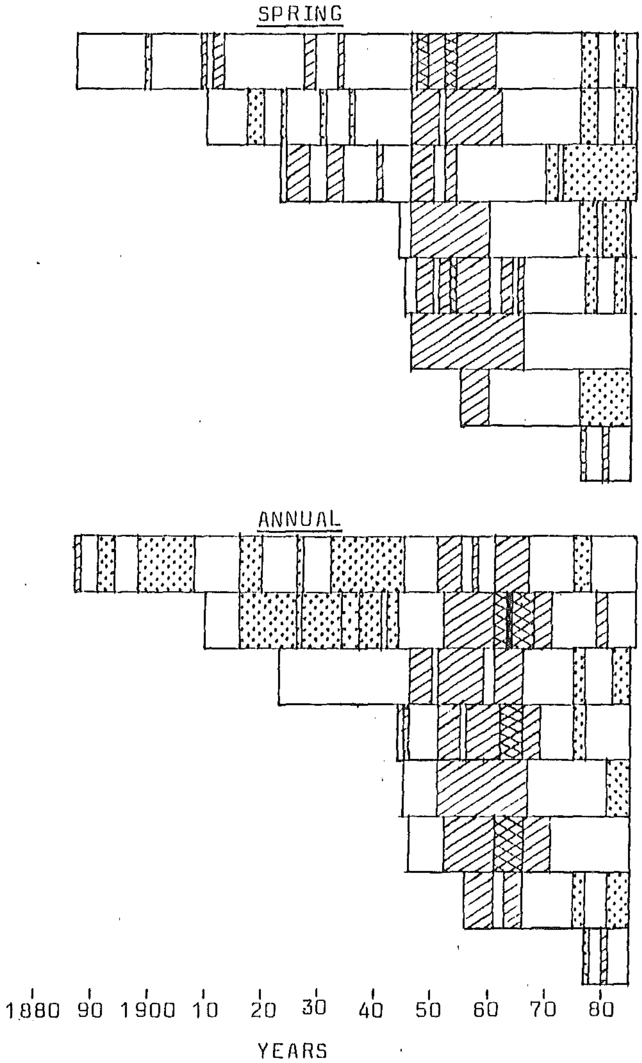


Figure 5.17 continue



area, has experienced a prolonged dry period from 1891 to 1944. The early 1910's was the only period when rainfall was consistently normal through-out the plains. It may also be possible that Banks Peninsula also experienced this dry spell. In contrast the 1950's to 1960's was the wettest period recorded in the study since records began. This relates to the 10 year scale wet period of the 1940's and 50's. Since 1965 conditions have become progressively drier despite the slight increase in rainfall around the late 1970's. This is due to the dry periods that occurred in the late 1960's to early 1970's, and the 1980's. The earlier dry spell shows up on the 10 year scale (Figure 5.12).

5.5.2 TEMPERATURE

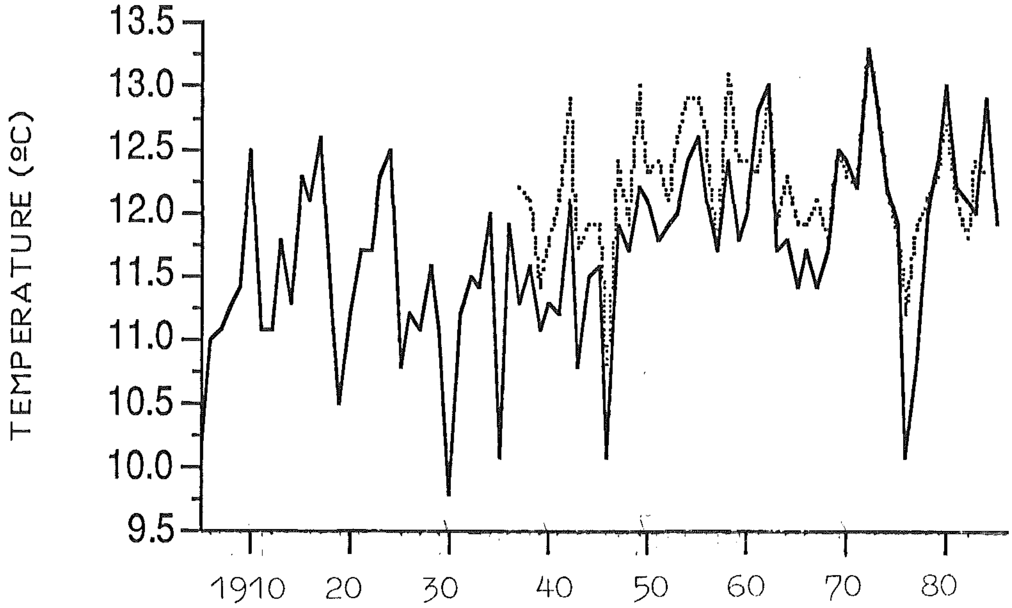
Maximum, minimum, and mean temperature will be looked in this part of the chapter. Graphs of the hottest and coldest months, seasonal, and annual temperature trends will be presented.

5.5.2.1 Climatic Record

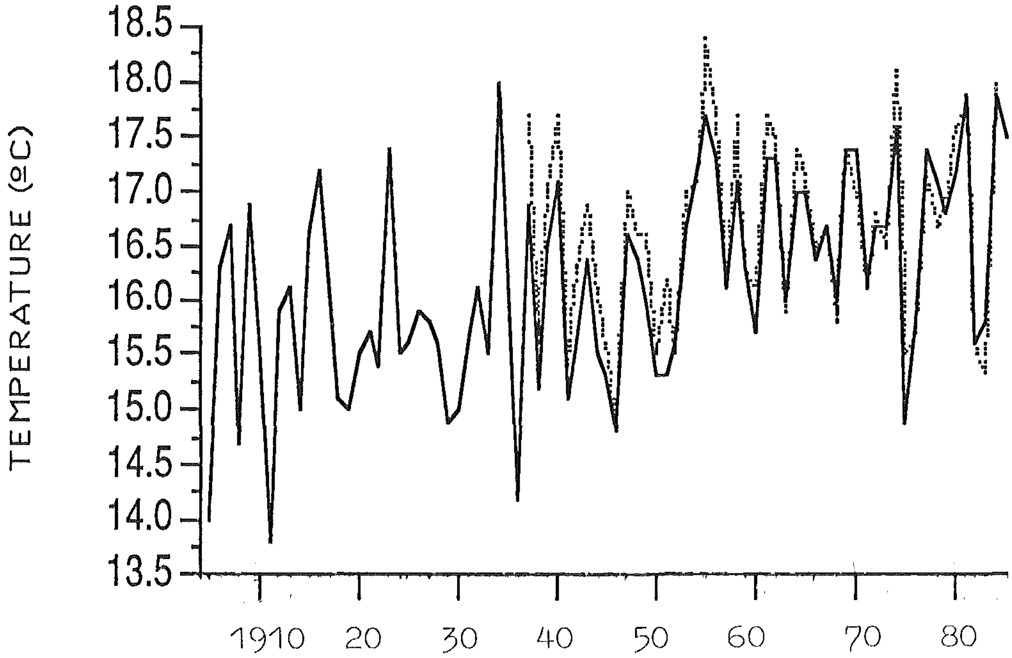
Figures 5.18 and 5.19 shows the annual and seasonal temperature of the following stations; Christchurch and Onawe. Onawe's record after 1972 has been estimated using the BMDP

FIGURE 5.18 CLIMATIC RECORD OF SEASONAL MEAN TEMPERATURES AT CHRISTCHURCH AND ONAWE

MEAN SPRING TEMPERATURES



MEAN SUMMER TEMPERATURES

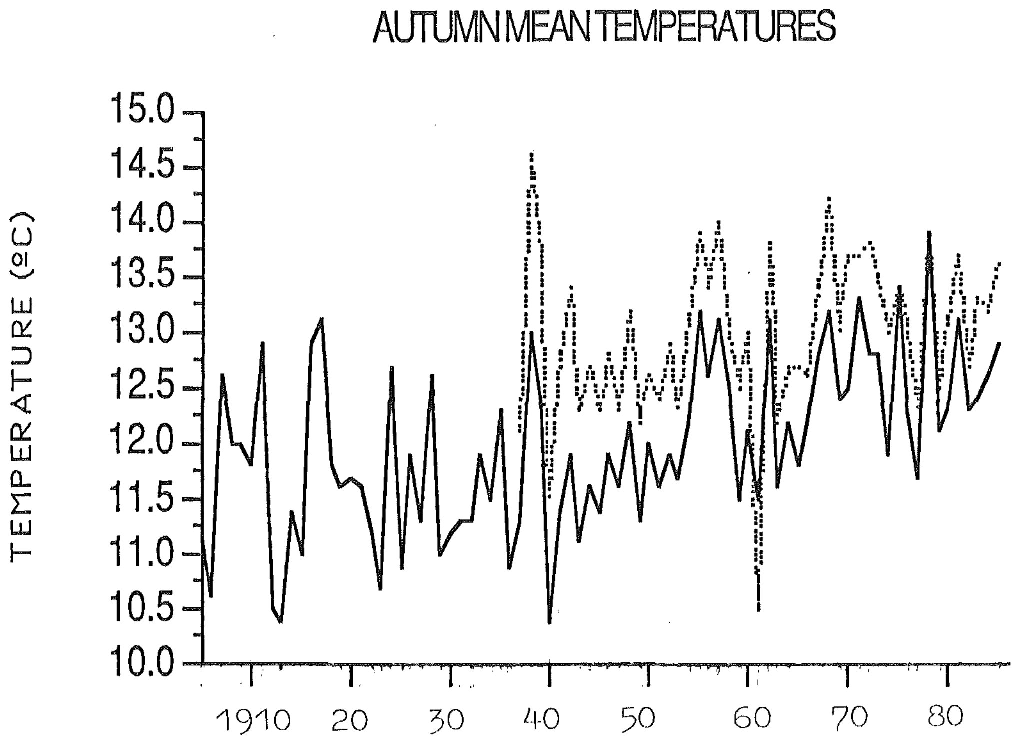


KEY

— CHRISTCHURCH

--- ONAWE

Figure 5.18 continue



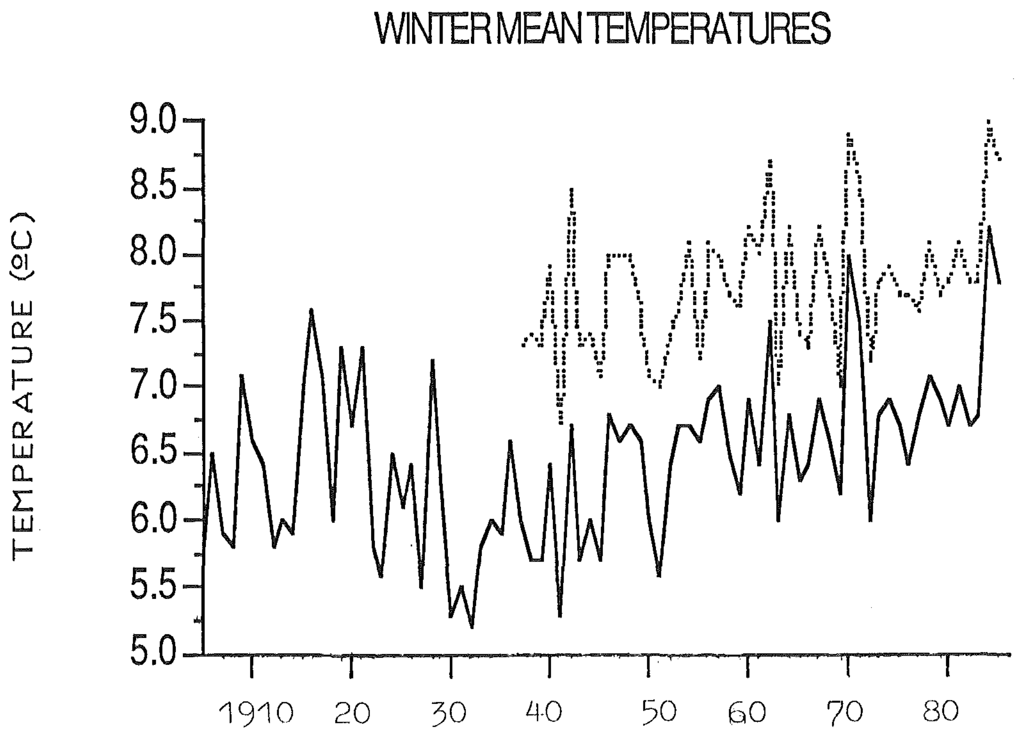
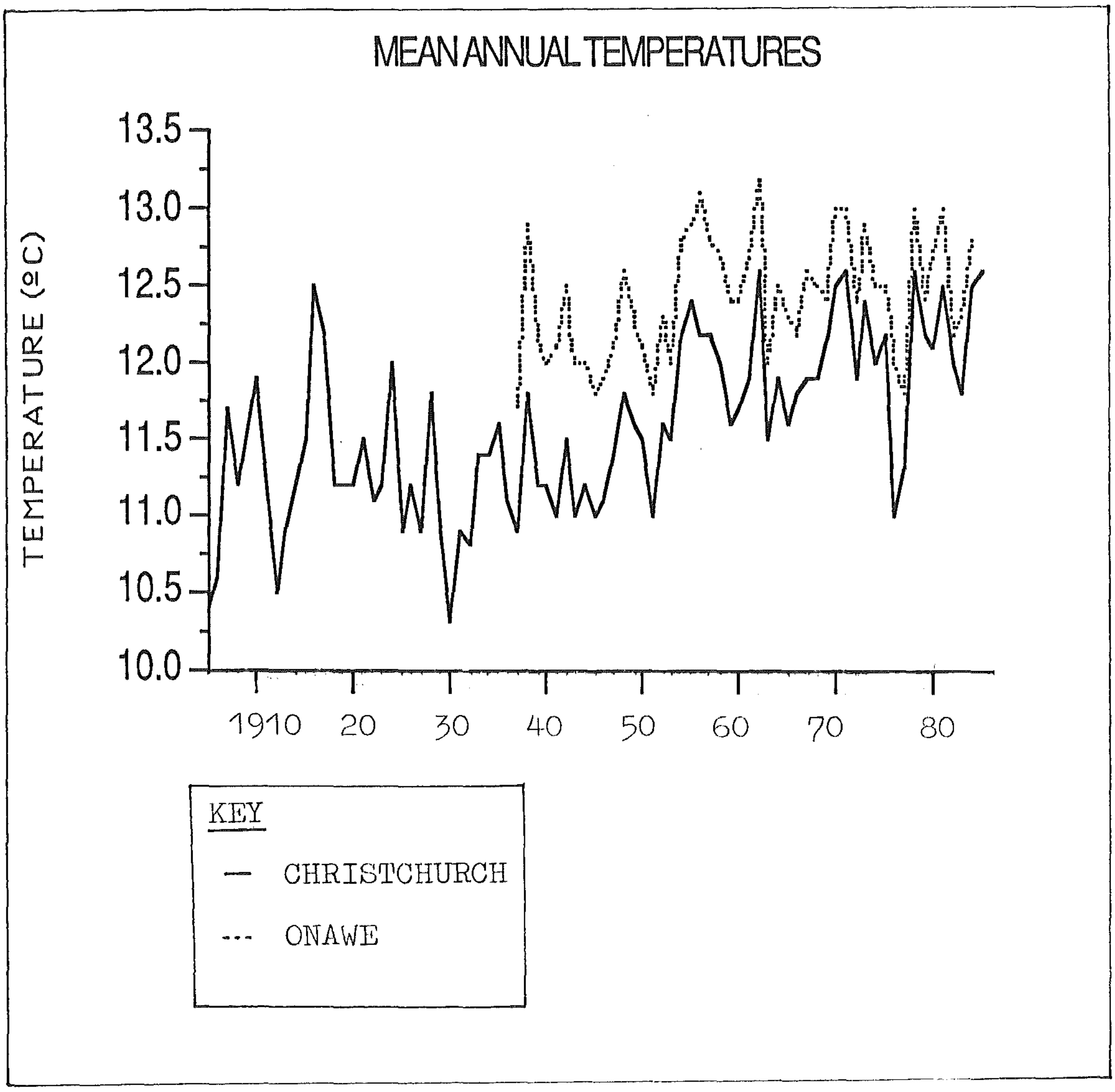


FIGURE 5.19 CLIMATIC RECORD OF ANNUAL TEMPERATURES AT CHRISTCHURCH AND ONAWE



"*Missing Value* " program. The figures indicate a cool period in the 1930's to 1945 with a subsequent warming since 1950. This warming, especially for the Christchurch station, is possibly the combination of two factors:

1) The warming of New Zealand's climate.

2) Changes in the microclimates of the station by non climatic elements causing a warming of temperature.

5.5.2.2 Ten Year Temperature Trends

Figures 5.20 to 5.21 shows the 10 year temperature trends in line graph form while figures 5.22 to 5.25 shows the spells of cooler, normal and warmer periods. The figures clearly show that up to approximately 1955 the study area, and most of New Zealand, experienced below normal to normal temperatures. The 1910's and the 1930's-40's were particularly cool periods. Maximum and mean temperatures were most affected by these cool periods whereas minimum temperatures were less affected. Since 1955 a marked temperature warming has occurred at all stations, especially maximum temperatures. Warmer than normal temperatures have occurred since 1960's. However, spring temperatures have recently shown a cooling trend.

One should take note of the wider variations that occur in minimum temperatures between the six stations, particularly in the

FIGURE 5.20 TEN YEAR MOVING TEMPERATURE TRENDS FOR THE WARMEST (JANUARY) AND COLDEST (JULY) MONTHS, AND ANNUAL TRENDS

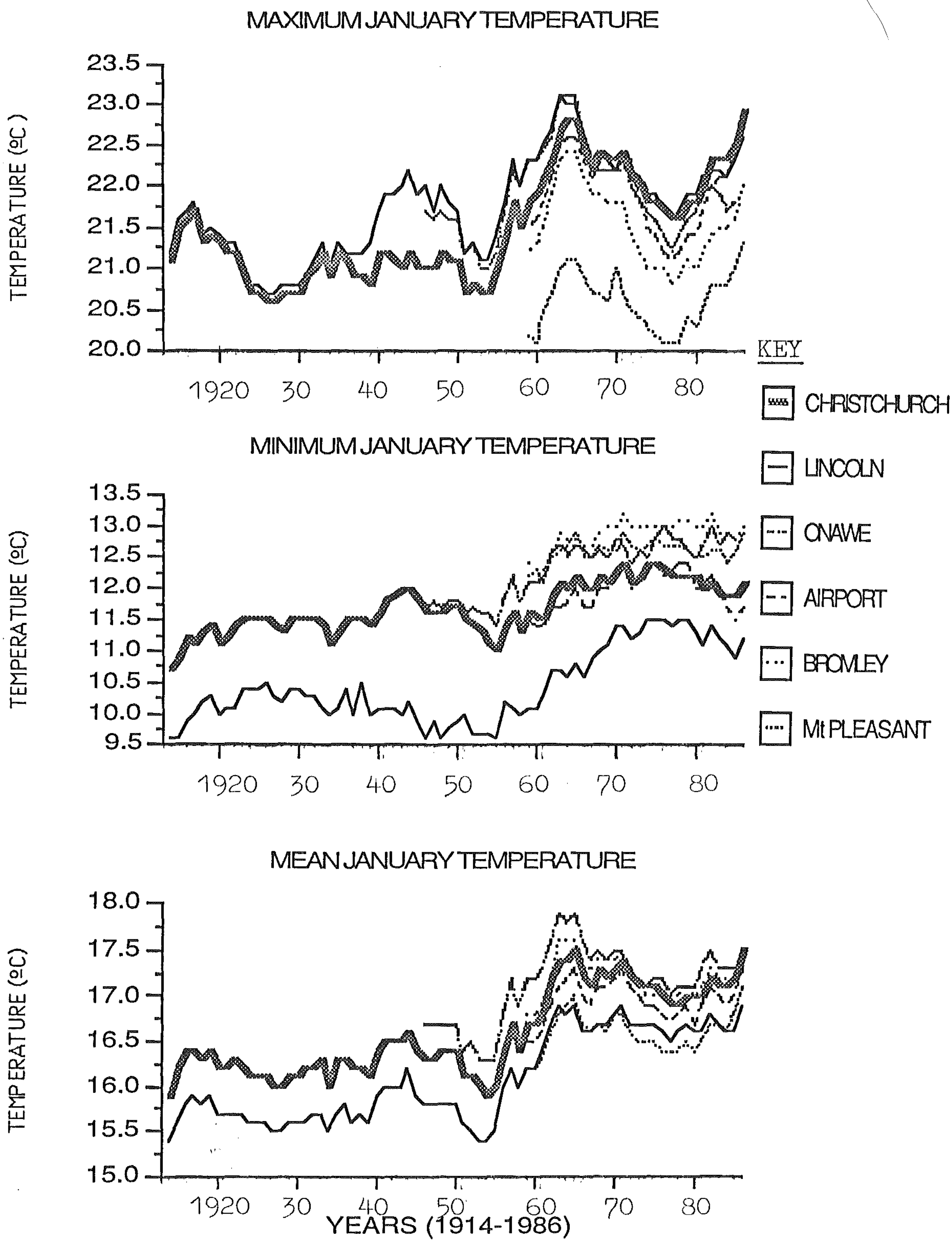


Figure 5.20 continue

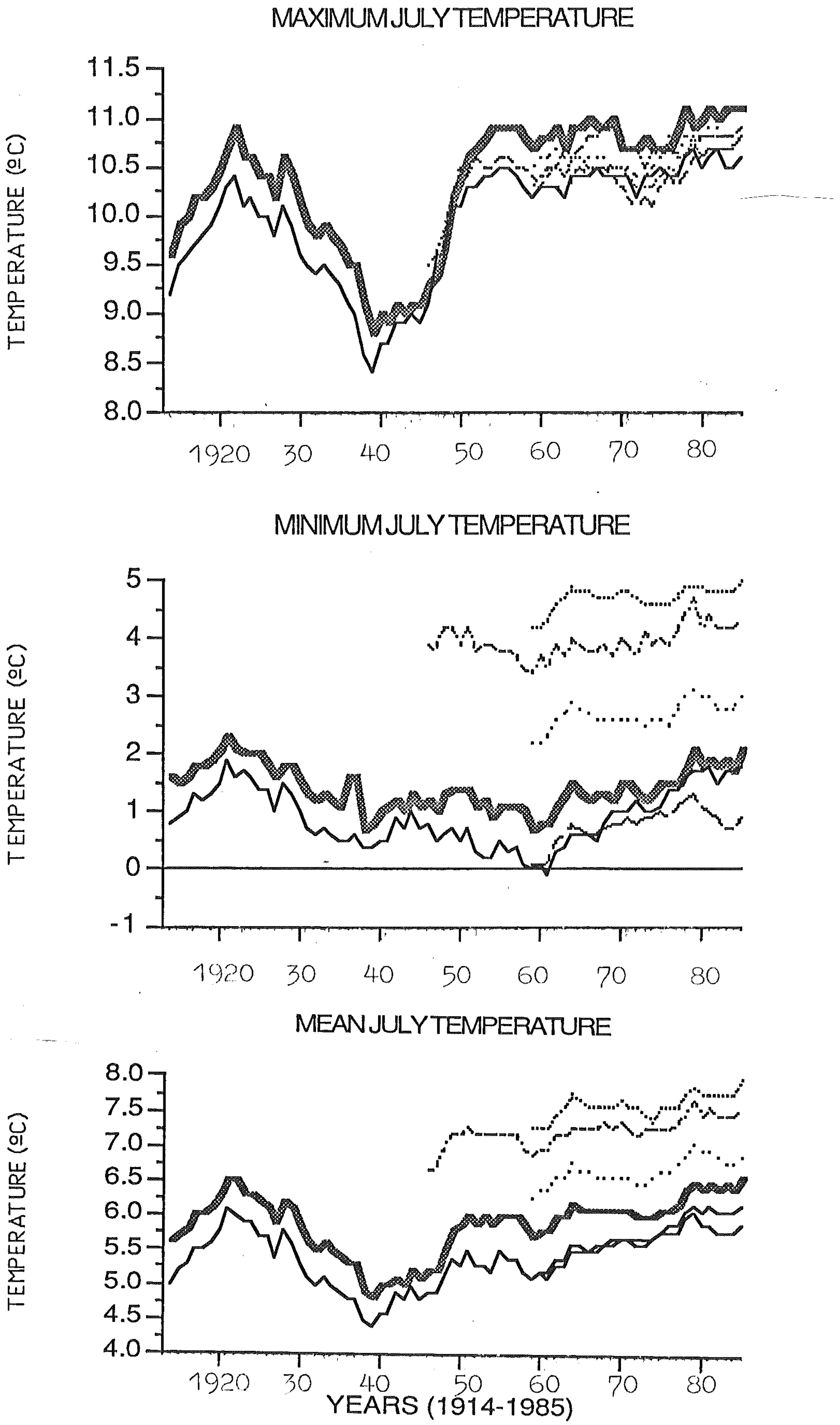
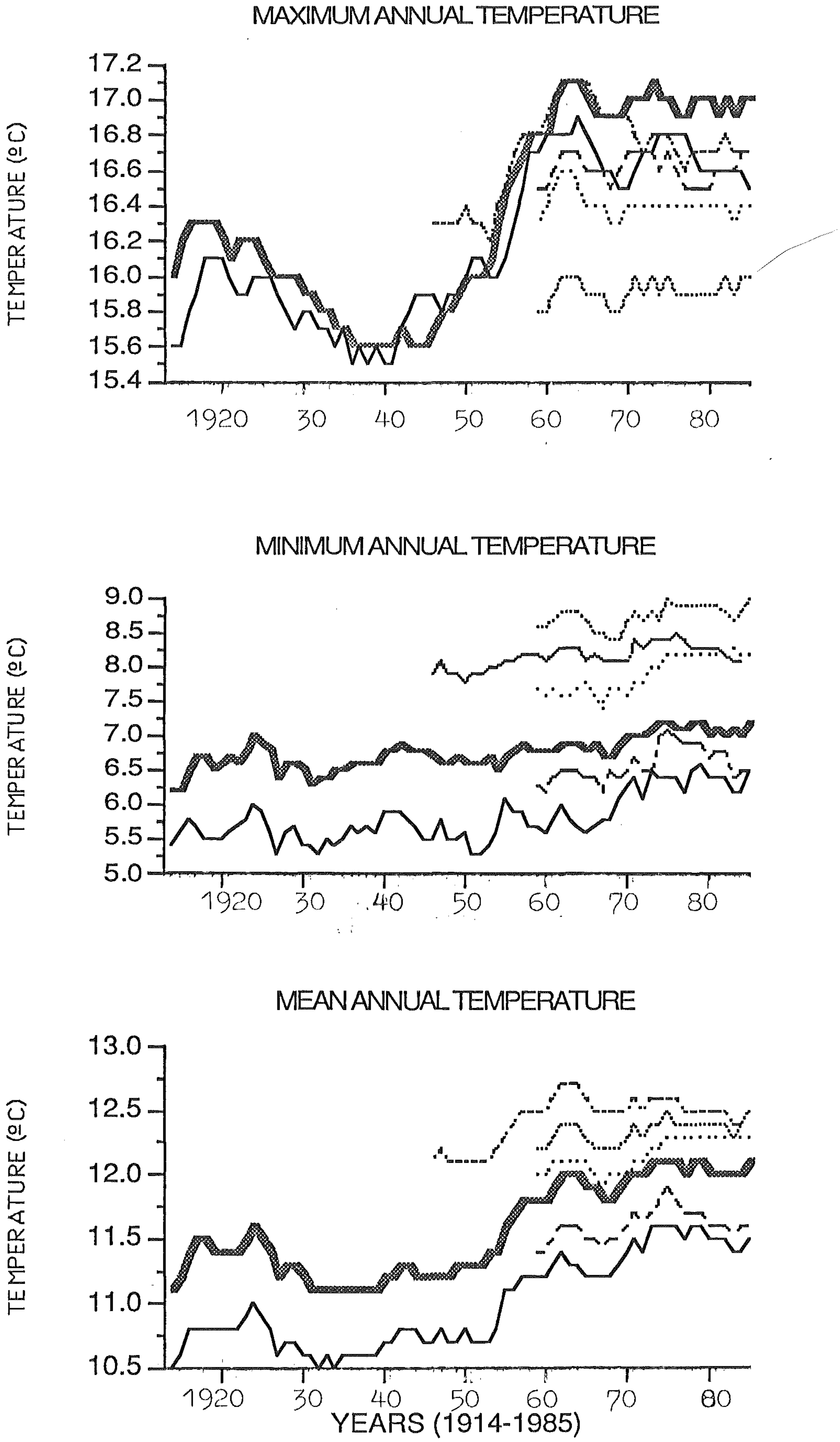


Figure 5.20 continue



colder months. Mount Pleasant has consistently the coolest maximum temperature but the highest minimum temperature.

Seasonal trends

When comparing the four seasons, they show similar temperature trends. This is particularly so for maximum and mean temperatures. However some slight differences occur between the four season's minimum temperatures.

For maximum temperatures the trends can be split into four groups:

1) Rising temperatures to around the mid 1920's after the cold conditions experienced around the turn of the 20th Century (Salinger 1980). This increase in temperature is particularly noticeable in winter and spring. The one noticeable difference is summer which seems to show stable temperatures at or below average from 1914 to 1955.

2) The cool period of the 1930's-40's. This cooler period began in the mid to late 1920's with the drop in temperatures and ends around the early 1950's. This cool period was particularly noticeable in winter and spring with at least an 1ºC drop in maximum temperature. As discussed before, the summer maximum doesn't display this cool period.

3) The rapid temperature rise of the 1950's and early 1960's.

This is the beginning of the post 1950 climatic warming suggested by various authors like Salinger (1980) and Trenberth (1980). It is during this period that the temperature is most rapid. Most seasons show a 1.5 to 2ºC rise in maximum temperature during this period.

4) Stabilisation or slowly changing temperatures of the 1970's to the present. Since the rapid temperature rise, the four seasons have shown different temperature trends. For winter and summer, maximum temperatures have become stable with some fluctuation around and above average temperatures. The cold summers of 1976 and 1977 can be seen by the reduction in maximum temperatures (Figure 5.20). The autumn maximum temperature has kept on rising but at a slower rate. Spring on the other hand has seen a declining temperature trend since the peak of the 1960's. Perhaps this is the first indication that the post 1950 climatic warming, suggested by Salinger (1980) and others, is coming to an end.

For seasonal minimum temperatures all seasons except winter show similar trends through-out the 1914-1985 period. The trend is one of gradual but steadily increasing minimum temperatures. There are fluctuations around this increasing temperature trend but not as great as the maximum temperature variations (Figures 5.22 to 5.25). Minimum temperatures approximately show an 0.5ºC difference between the lowest and highest recorded minimum temperatures in

FIGURE 5.21 10 YEAR MOVING TEMPERATURE TRENDS ON A SEASONAL BASIS AT SIX STATIONS

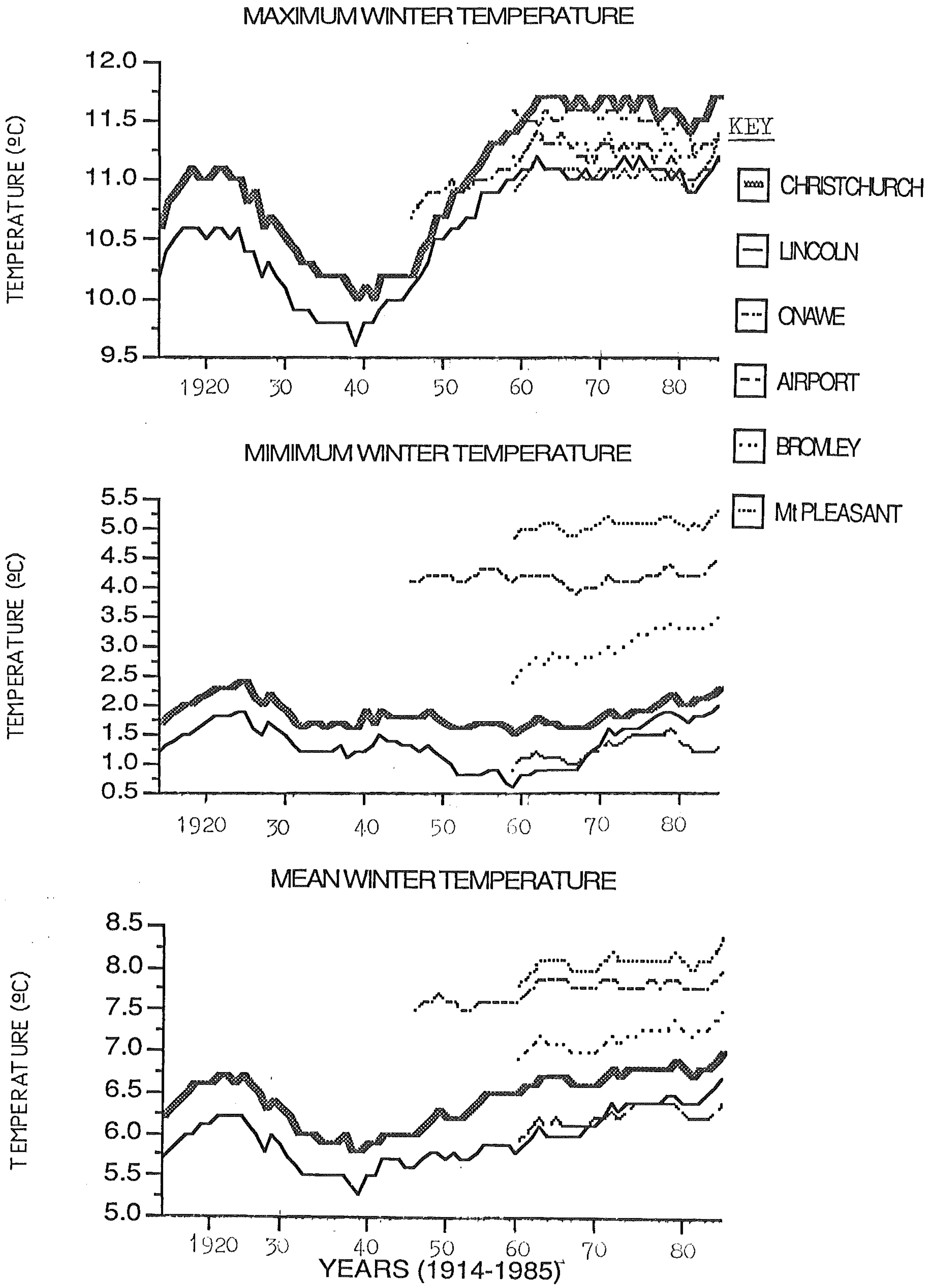


Figure 5.21 continue

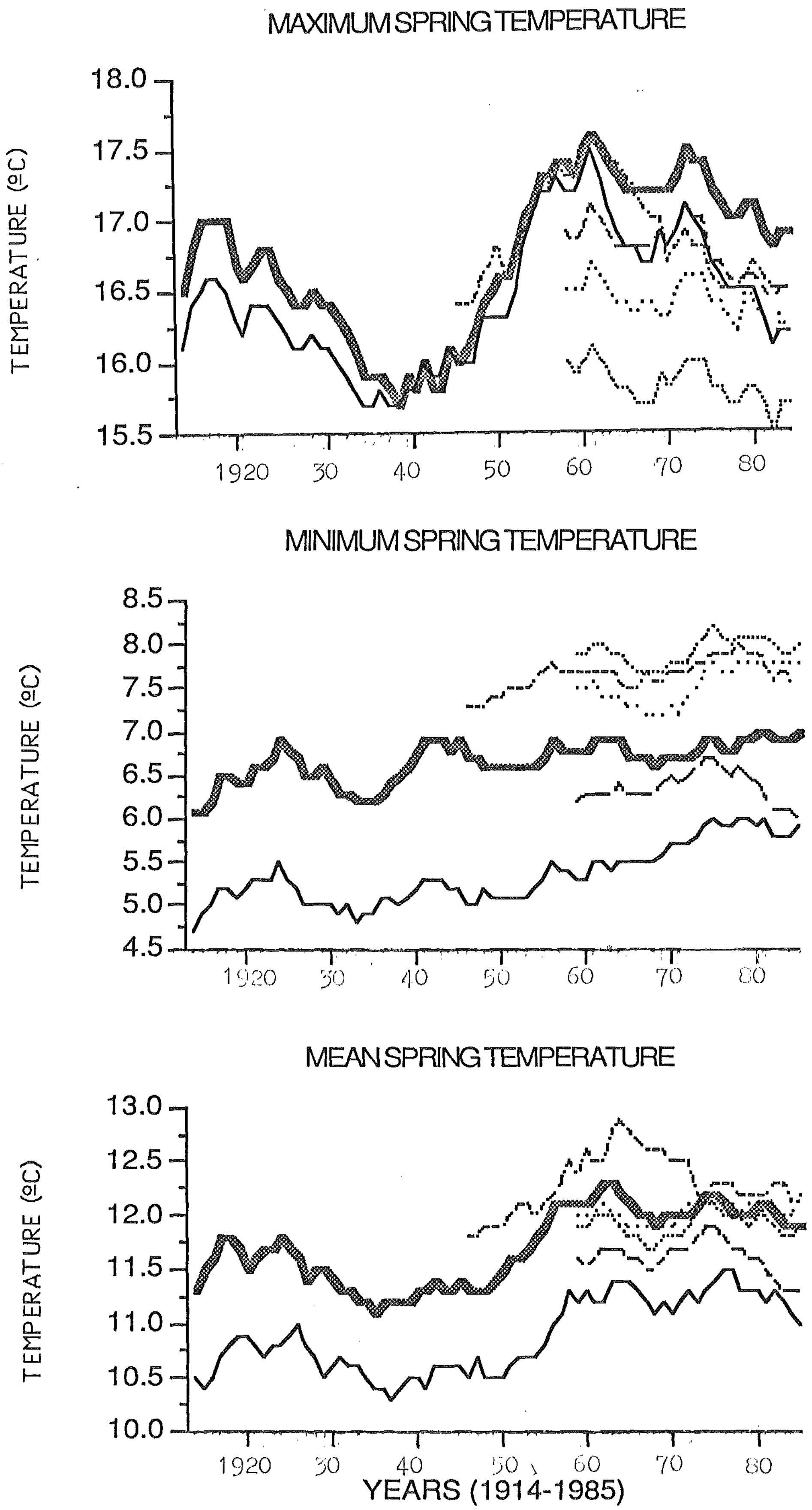


Figure 5.21 continue

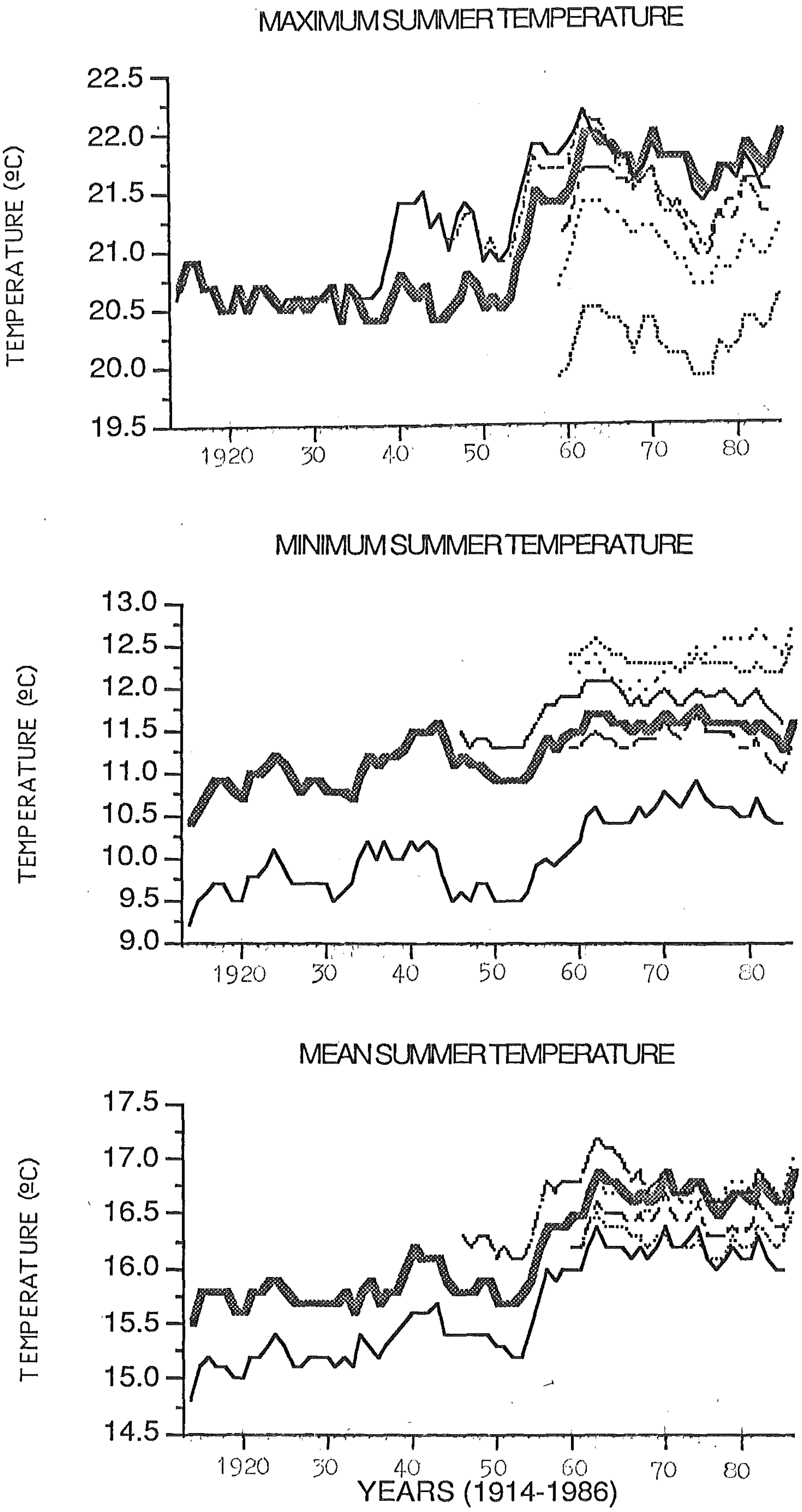
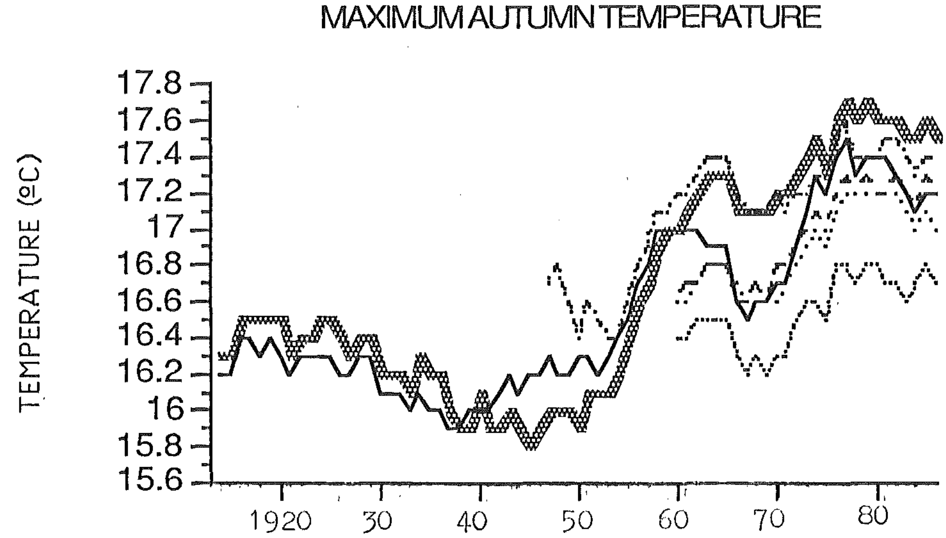
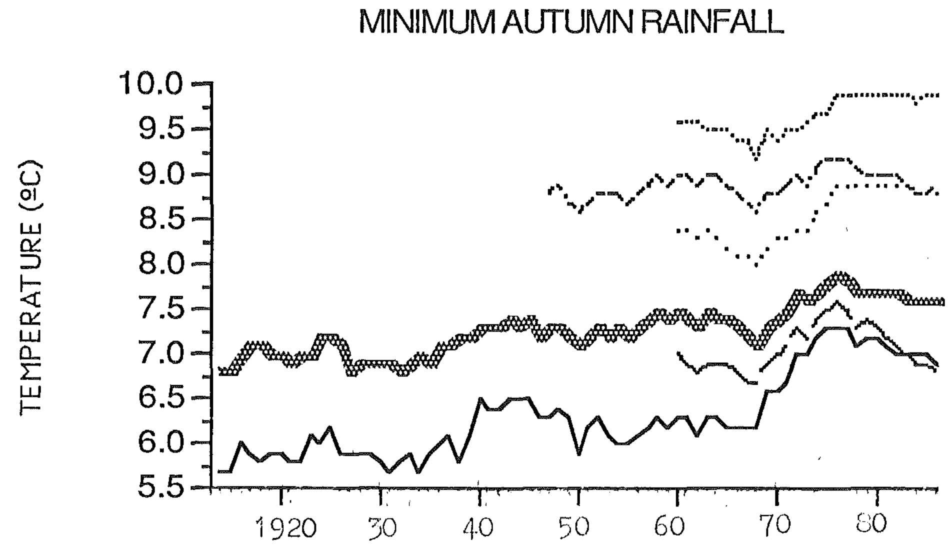
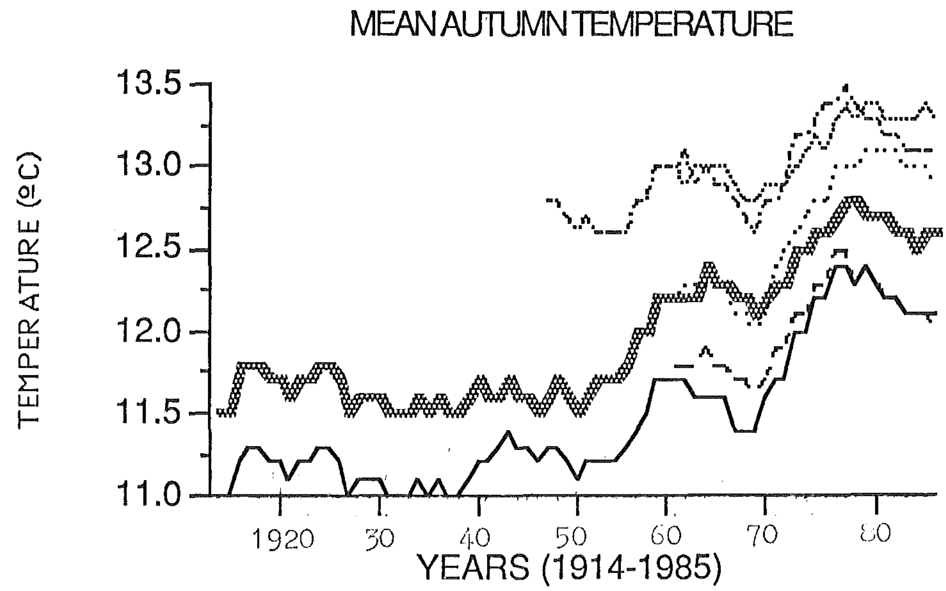


Figure 5.21 continue







all seasons. The winter minimum temperature is quite different to the others showing increasing temperatures to the mid 1920's then slowly decreasing temperature trends to the 1960's. Since the 1960's winter's minimum temperature has steadily increased.

In terms of seasonal mean temperature trends, most of them follow their seasonal maximum temperature trends. However its variation is less extreme when compared to the maximum temperature variation.

Annual trends

Maximum and mean annual temperature trends can be broken into four periods:

1) 1914-1927: Increasing temperature trends reaching a peak in the mid 1920's.

2) 1928-1950: Decreasing temperature trends reaching its coolest period in the late 1930's to early 1940's.

3) 1950- early 1960's: Rapid increase in temperature.

4) Stabilization or slowly increasing temperature since the mid 1960's.

In terms of minimum annual temperature it has slowly but steadily increased since the 1930's.

5.5.2.3 Thirty Year Trends

The 30 year trends show very similar temperature trends to

FIGURE 5.22 THE OCCURRENCE OF COOL, NORMAL, AND WARM SPELLS (10 YEAR MOVING TRENDS) FOR THE WARMEST (JANUARY) MONTH OF THE YEAR AT SIX STATIONS

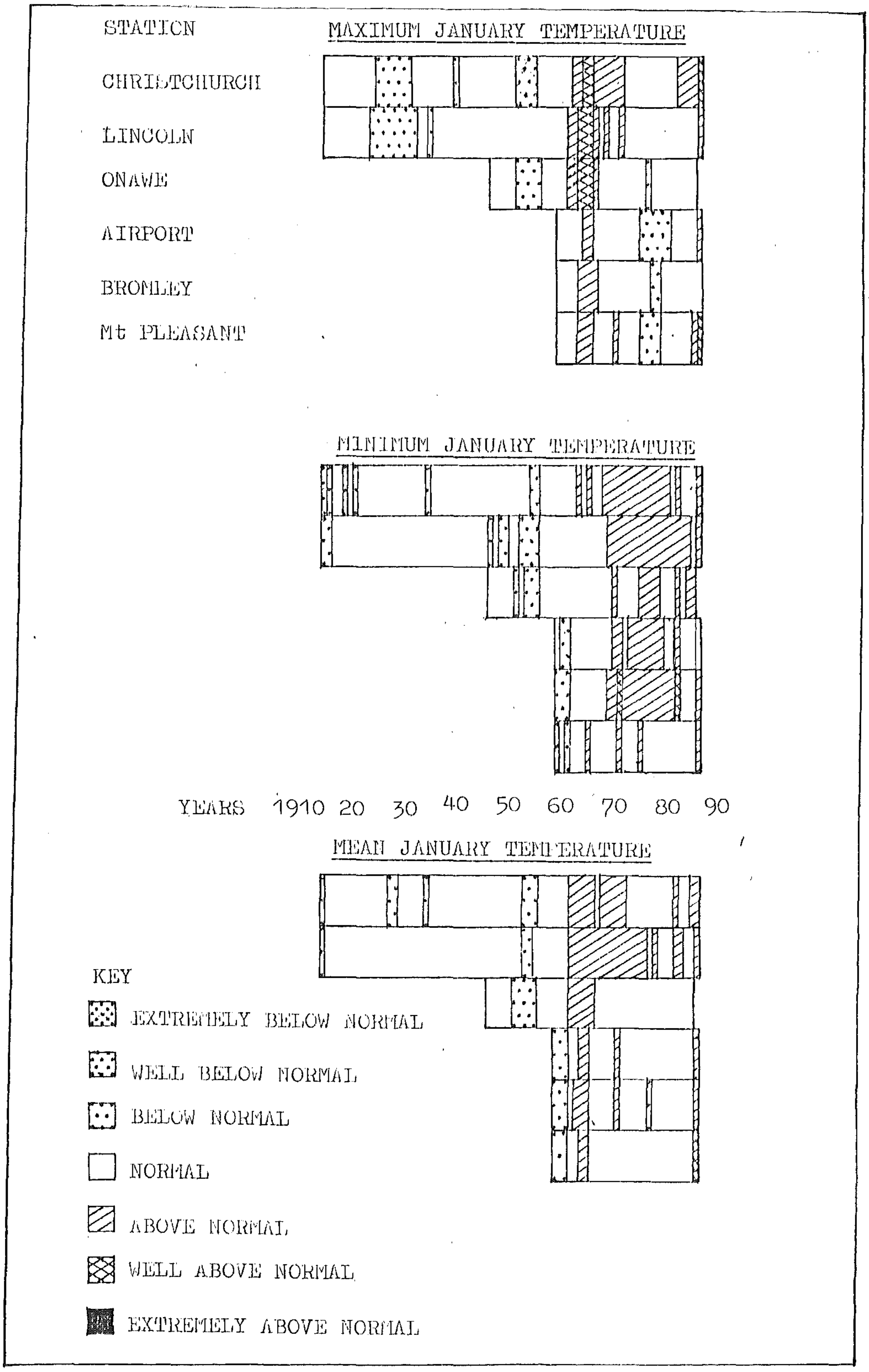


FIGURE 5.23 THE OCCURRENCE OF COOL, NORMAL, AND WARM SPELLS (10 YEAR MOVING TRENDS) FOR THE COLDEST (JULY) MONTH OF THE YEAR AT SIX STATIONS

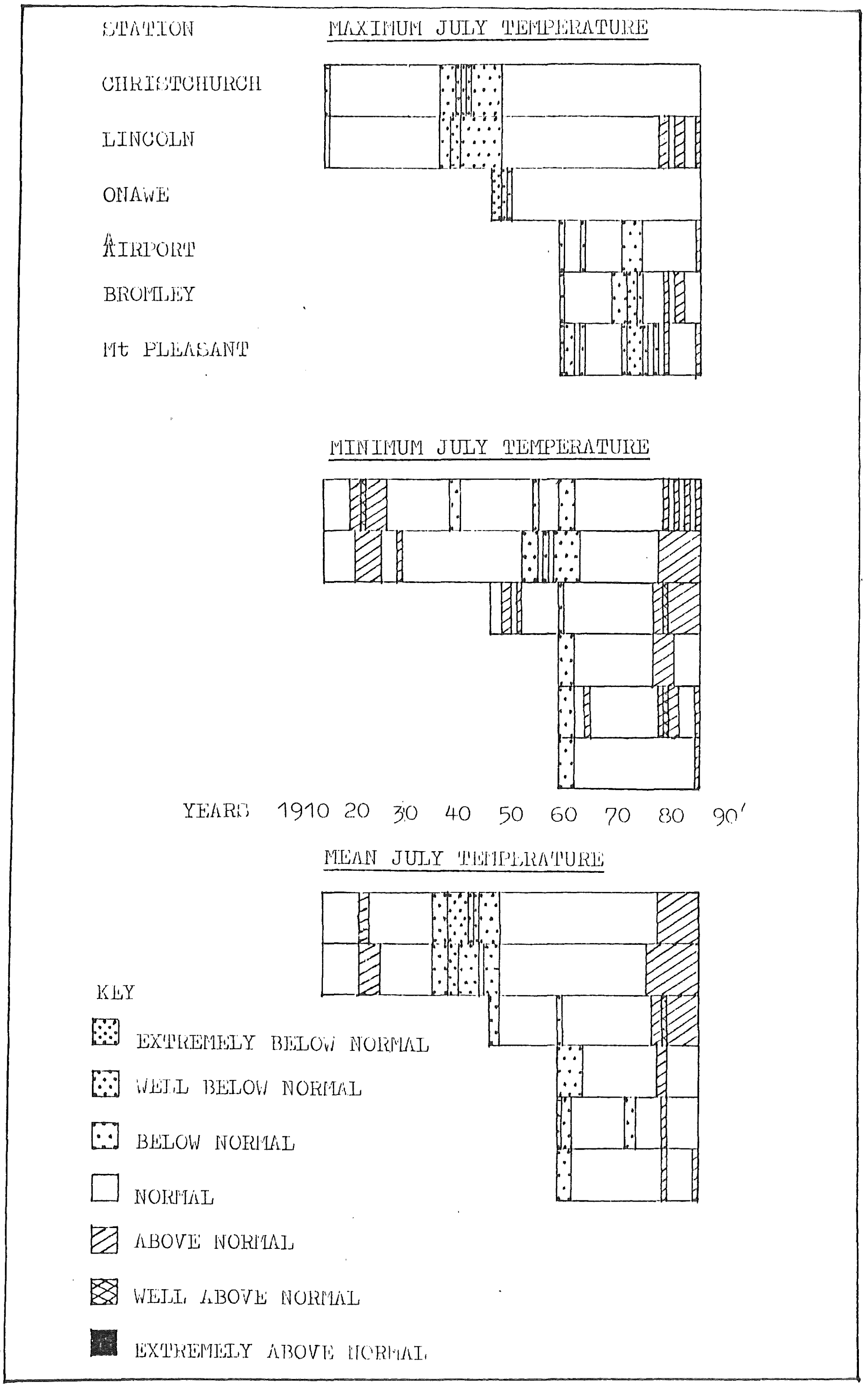


FIGURE 5.24 THE OCCURRENCE OF COOL, NORMAL, AND WARM SPELLS (10 YEAR MOVING TRENDS) ON A SEASONAL BASIS AT SIX STATIONS

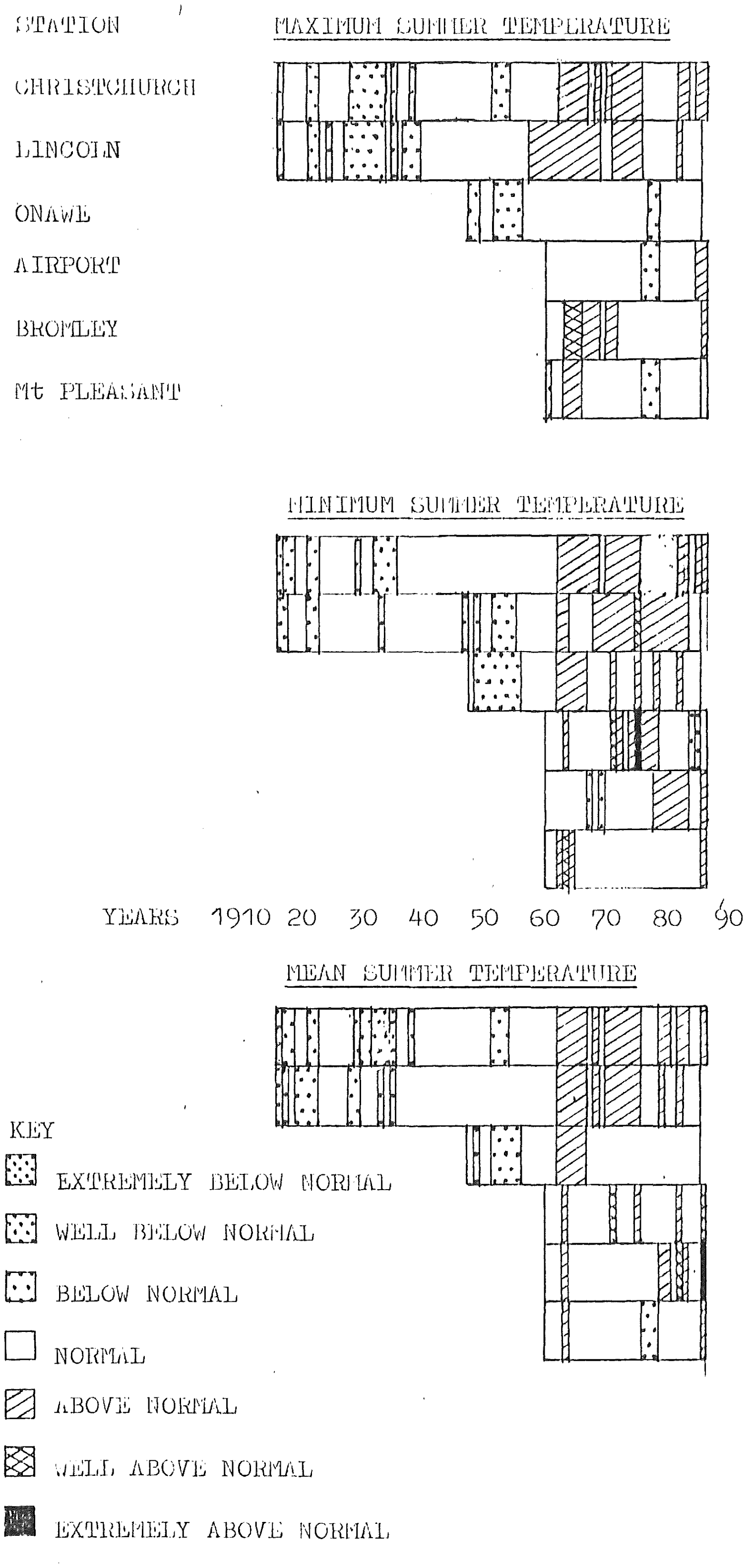


Figure 5.24 continue

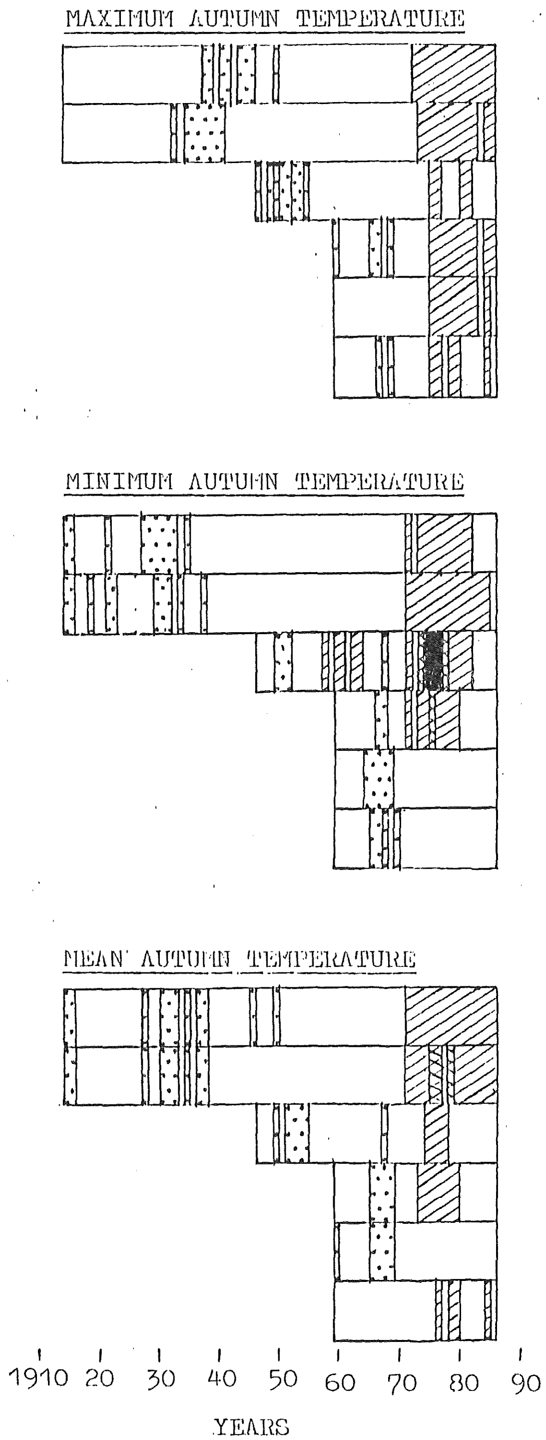


Figure 5.24 continue

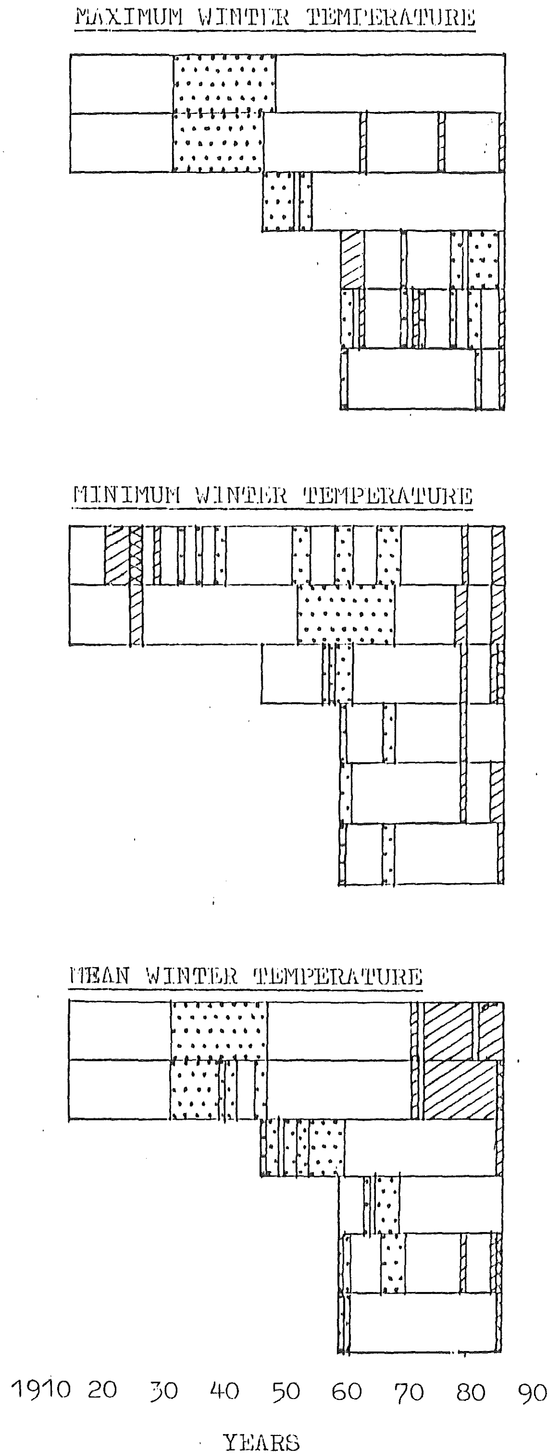


Figure 5.24 continue

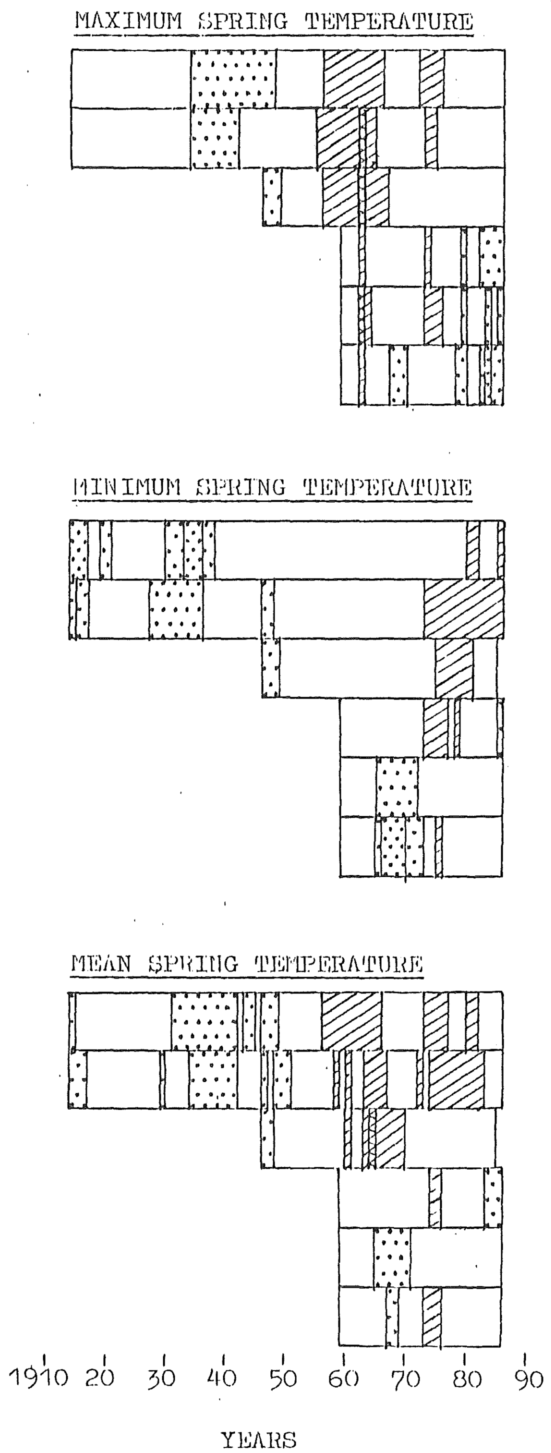
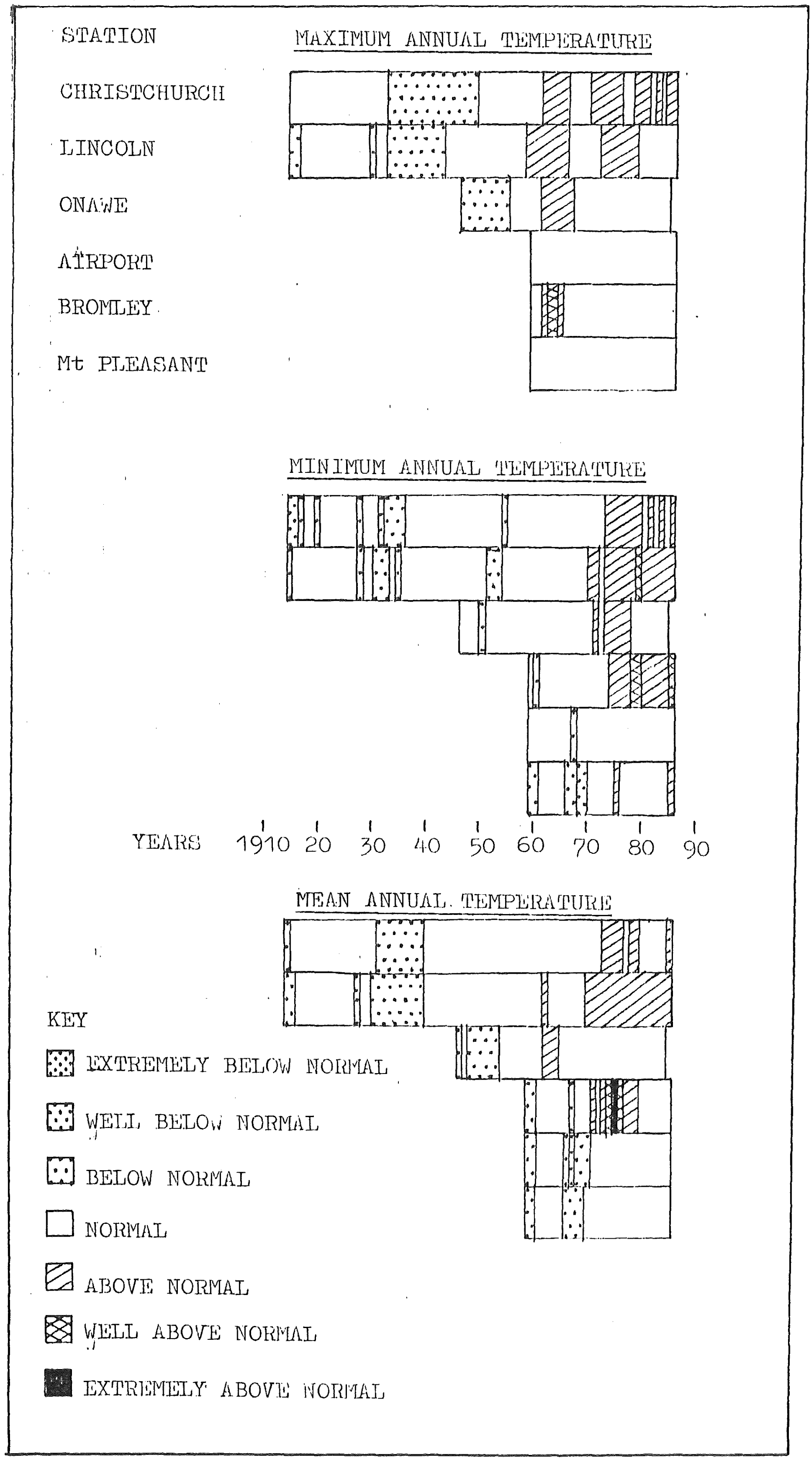


FIGURE 5.25 THE OCCURRENCE OF COOL, NORMAL, AND WARM SPELLS (10 YEAR MOVING TRENDS) ON A ANNUAL BASIS AT SIX STATIONS



those shown in the 10 year trends. As you would expect the 30 year temperature trends respond slower to the 10 year temperature trends by aprroximately 5 to 10 years, and is less extreme in terms of fluctuations and the range between the lowest and highest recorded moving temperature average.

5.6 HISTORICAL DATA

Previous research (Salinger 1980) has shown that the early 1860's and the years around 1900 to be the coldest period experienced in New Zealand since instrumental records began. Salinger and others have suggested that a climatic warming has occurred since 1950 with temperature warming of 0.6ºC.

This author is mainly concerned with rainfall trends since 1867, and temperature trends since 1914. One good source to validate the results shown in the rainfall and temperature trends is in historical writings, such as newspaper and people's personal experiences. Clarence Hodgson recently gave a talk on climatic conditions experienced in Canterbury since 1840, from which a manuscript has been prepared.

5.6.1 Rainfall

The rainfall trends suggest that Canterbury had experienced a wet period up to 1870. This is indicated by water up to knee height in the Cathedral Square in 1868 by Hodgson and in The Press newspaper in February 1868:

"*The late rains, a great deal more of which must have falled upon the hills than we had in Christchurch, have caused such floods in the Waimakariri and Selwyn as never before been known. The overflow of the Waimakariri found its way into the Avon, and laid all the low lying parts of the city along its banks under water.* "

Hodgson discussed rainfall events that occurred around Christchurch. The following points were brought up in his discussion supported by newspaper extracts:

1) A heavy rainstorm over Lyttleton which washed away six houses indicates that heavy rain can occur at any time irrespective of the general rainfall trends. This rainstorm was indicated in "The Press" newspaper in May 1923 with heavy flooding in Banks Peninsula and on the Canterbury Plains:

"***Record Rainfall.***

Floods Throughout Province

Widespread Damage

The rainfall in Canterbury from Friday to yesterday afternoon is stated to be the heaviest for over twenty years, as far as the *province is concerned, and a record for the city. It has been responsible for floods all over the province owing to the rivers and creeks being unable to carry off the volume of water which poured down from the hills.*

Floods at Akaroa

The rain that set in on Thursday evening had, by sunset on Saturday, settled down to what is commonly regarded as 'an old-fashioned southerly". And it continued so right through Sunday and so on up till the time the mail closed yesterday, when there was not the slightest sign of its lifting. The continued downpour has flooded all the creeks. Some of them are already over the banks. Every depression on the hillsides is sending down a rushing, turbid stream; and minature cascades and waterfalls are largely in evidence. Low-lying areas are flooded and stock have been removed. "

2) 1931 to 1934 period was a dry period. Rainfall trends indicate this.

3) The 1935 to 1939 period was very wet. 1945 was a very wet year with floods on the East Coast. 1950 and 1951 summers were wet. In 1951 Christchurch recorded 1041mm of rainfall. Table 5.1 shows the floodings that occurred in Kaituna Valley from 1934 to 1955. These points indicate the wet period of the 1940's and 1950's as well as Table 5.2 which shows the occurrence of floods in Kaituna

TABLE 5.2 FLOODING IN THE KAITUNA VALLEY FOR THE 1934-1954 PERIOD

DATES OF FLOODS IN THE KAITUNA VALLEY.

Date.		Length of flooding.
1934	May 4th. 5th. and 6th.	2 days
	September 26 and 27	2 "
1935	September 9	1 day
1936	February 8 and 9	1 "
	February 20	1 "
	March 9	1 "
	July 23	1 "
	November 30	1 "
1937	May 16 and 17	2 "
	December 17 and 18	2 "
1938	June 12 and 13	2 "
1939	December 27	1 "
1940	January 12	1 "
	May 7 and 8	2 "
1941	March 19 and 20	2 "
	August 16 and 17	1 "
1942	May 24 and 25	2 "
1943	July 13 and 14	2 "
	September 9	1 "
1944	No flooding	
1945	May 18 19 and 20	3 "
	August 8	1 "
1946	May 27	1 "
1947	June 21	1 "
	October 30	1 "
1948	January 11	1 "
1949	No flooding	
1950	October 31	1 "
1951	January 25	1 "
	February 9 and 10	2 "
	March 2	1 "
	March 11	1 "
	April 2	1 "
	April 26	1 "
	May 22 and 23	2 "
1952	August 10	1 "
	August 14	1 "
	October 21	1 "
	November 8	1 "
1953	January 25	1 "
	August 18	1 "
	October 9 and 10	1 "
1954	May 19	1 "
	August 15	1 "

Notes.

(1) Floods of May, 1934, May 1935 and February 1951 complete inundation of all flat land in the valley.

(2) Floods of May 1934 and February 9th. 1951 washed away Church bridge.

(3) Im May 1945, Burrows and Henderson's (Dairy) houses flooded and in the Kaituna Hall. Flooding over the road above the bush which also occurred in February 1951.

(4) All floods including the above three, flooding over the road, between Poplars and Hendersons and at the Main Road junction of the Valley Road.

All the above information on flooding in the Kaituna Valley taken by Mr. K. Parkinson from his diaries.

Valley for the period 1934 to 1954.

4) Very heavy rainfall around Banks Peninsula during the Wahine Storm are part of the wet autumn spell in the 1960's and 1970's.

The droughts of the early 1970's and 1980's were also reported in the newspaper. They were mainly concerned with the effects the drought had on the farming community and the need for irrigation systems in Canterbury.

5.6.2 Temperature

Salinger (1980) and Hodgson have discussed the various climatic events affected New Zealand and Canterbury. The following is a list of the significant events:

1) many severe winter snowfalls and heavy frosts were reported in 1860, 1863, 1867, 1878, 1879, 1888, 1895, 1903, 1911, 1913, 1918, 1939, and 1945. Periods with many severe storms occurred between 1860's-80's and 1920's-40's (Salinger 1980).

2) 1867 saw severe snowfalls on the Canterbury Plains, up to 1m deep.

3) In 1886 a foot of snow fell in Christchurch.

4) Lyttleton Harbour was frozen over in 1895 after a month of hard frosts.

5) In 1903 a severe winter occurred in the inland areas of the

SouthIsland with Christchurch having odd falls of snow. Chuncks o ice were reported flowing down the rivers in September.

6) 1918 saw heavy snowfalls in Canterbury. Snow fell i Christchurch on the 6th, and 17th of July with a foot of snow. Th following are extracts from the The Press about these two events:

"***WIND, SNOW, AND RAIN***

WILD WEATHER IN CANTERBURY.

It is many years since more typically wintry weather has beer experienced in Canterbury than has marked the last few days, anc culminated on Sunday and yesterday in conditions that nearly approximated to the Antarctic in their intensity.

Not since 1909 has there been such a heavy fall of snow in the South Island, when there were considerable losses of sheep in South Canterbury and Otago. Prior to those there were still more severe snowfalls in 1893, 1895, and 1903, all of which were disastrous to sheep owners in the back country." (7th July)

"The citizens of Christchurch will long remember July 21st, 1918, as being the date of the roughest day and heaviest snowfall known here for the past score of years at least. During the night the temperature fell, and at an early hour yesterday morning the whole city and suburbs were covered witha two to three inch mantle of

white snow. " (21st July)

7) The winter of 1939 was the worst winter on Banks Peninsula for 50 years with the Eastern Bays isolated by snowdrifts 30 feet deep on the summit roads. Christchurch received five snowfalls of 2 to 4 inches thick.

8) The heaviest snowfall recorded in Christchurch occurred in July 1945 being up to 18 inches thick. Severe frost, and the lowest recorded minimum air temperature, following the snowfalls allowed ice skating on Little Lake Victoria in Christchurch. The following are extracts from The Press:

"RECORD SNOWFALL IN CHRISTCHURCH

WIDESPREAD DAMAGE TO COMMUMICATIONS

The heaviest snowfall ever recorded in Christchurch covered the city and suburbs to depths varying from 7 to 18 inches in the brief period between 1 o'clock and daylight on Saturday morning. Heavy falls were general in the country districts of Canterbury, but such was the severity of the damage to telegraph and telephone lines - the worst in the history of the Post and Telegraph Department - that up to last evening it was impossible to make any accurate assessment of the extent of the material damage and losses of stock.

RECORD FALL AT LYTTELTON

Depths up to two feet

In the early hours of Saturday morning, Lyttelton had the heaviest snowfall yet recorded. Snow began about 1a.m. and by 3 a.m. there was nine inches of snow on the wharves, while in the higher parts of the town there was a fall of from18 to 24 inches. A lighter fall then continued for three or four hours and further increased the depth by an inch or more." (15th July)

9) Large snowfalls also occurred in 1935, 1943, and 1973 on the Canterbury Plains.

The above historical evidence indicates that since 1950 the study area, as well as New Zealand, experienced a climatic warming. The only significant snowfall in Canterbury since 1945 was in August 1973, and on Banks Peninsula in 1983 when 15 foot snowdrifts were reported. The 1983 snowfalls, the heaviest for the past 20 to 30 years, occurred arter an extreme negative phase of the Southern Oscillation experienced in 1982-83. Hodgson suggested that the heat from the Christchurch urban area has been cutting out the regular snowfalls in Christchurch since 1945. Hodgson's observations along with Hessells work (1980) support the idea that the climatic warming since 1950 has resulted from two factors:

1) Non-Climatic Events - modification of the microclimate around theclimate station like sheltering from trees and buildings, and the urban heat island effect.

2) Climatic Events - changes in the terrestrial factors like atmospheric circulation and water temperatures around New Zealand. Perhaps extra-terrestrial factors like solar radiation and sunspot activity may also have been responsible to the present warming trend in New Zealand climate.

5.7 CONCLUSION

Since instrumental records began the study area's climate has fluctuated quite widely. Temperature, as indicated by Salinger (1980), in Canterbury has followed a similar trend to other areas of New Zealand. Rainfall on the other hand, is probably more regional.

The study area has largely been dominated by normal to dry rainfall conditions as indicated by the 10 and 30 year moving trends. The 1940's to 1960's were the wettest period recorded in the study area since 1867. However 1974 to 1980 period was very wet especially for winter rainfall, and was the wettest period on the 10 year scale. Results show that Banks Peninsula's rainfall trends fluctuate much more widely than the surrounding plains area. This is especially so of the high rainfall regions. The locations of Banks Peninsula makes it sheltered from moist westerly quarter airstreams. However it is more vulnerable to rainbearing winds from thesouthwest to the northeast than the surrounding plains area. This has meant that Banks Peninsula can experience very dry to very wet conditions.

A very cool period dominated the region's climate from the late 1920's to approximately 1945 with severe winters and significant snowfalls. Yet this cool period was not as cold when compared to the 1860's and the years around 1900. Historical data also indicate these periods as being cool. Climatic warming has occurred since 1950 but changes in the microclimate sorrounding the station sites has also contributed to this warming trend. Only one significant snowfall has occurred in Canterbury since 1945. Results show that maximum temperature is more significantly affected by climatic changes in the study area than minimum temperature.

CHAPTER SIX

SYNOPTIC FLOW INFLUENCES ON RAINFALL AND TEMPERATURE TRENDS

6.1 INTRODUCTION

Various studies have been conducted in the Canterbury region primarily looking at the influence of atmospheric circulation on rainfall distribution and patterns over Canterbury. Most studies have examined the impact of atmospheric circulation on rainfall patterns on a daily to yearly scale (Trewinnard and Tomlinson 1986, Sturman 1986). Regional classification of rainfall in Canterbury was conducted by Salinger (1979) while Goulter (1982) looked at the spatial variation of the wettest month. No studies, to the authors knowledge, have looked at the influence of longer term synoptic flow changes on rainfall and temperature trends in the Canterbury region.

Major factors influencing the distribution and patterns of rainfall and temperature trends over the study area include the frequency and occurrence of synoptic features such as depressions and fronts, and airstream direction. If synoptic flow patterns show a trend of increasing cyclonic activity with increasing rain-bearing winds, one would expect the rainfall trend to show a rise. A reverse of the above situation should result in a decreasing rainfall period. It would expected that synoptic circulation provides the broad scale control on rainfall and temperature trends but local features may also be important in the study area, such as exposure to rain-bearing winds and alitude.

The aim of this chapter is to examine the impact of synoptic flow patterns at three scales using multiple regression analysis:

1) To determine which circulation patterns have a significant impact on monthly, seasonal, and annual rainfall and temperature.

2) To identify the influence of synoptic flow changes on rainfall and temperature trends on a 10 year moving trend scale.

3) The above, but at a 30 year scale.

Indices of Atmospheric circulation (Sturman et al 1984) are used in the multiple regression analysis. This is to determine which of the five circulation types have a significant influence on rainfall and temperature trends. A description is given of the synoptic flow changes using 10 and 30 year moving trends.

6.2 PREVIOUS RESEARCH IN NEW ZEALAND

Relatively little research has been conducted in New Zealand concerning the relationship of changes in synoptic patterns in New Zealand to rainfall and temperature trends. Watts (1947) looked at the relationship of New Zealand's weather and climate to the westerlies. This study only considered daily weather patterns and looked at the distribution of rainfall over New Zealand under various synoptic airflows. Trenberth (1976) examined the fluctuations in atmospheric circulation over the Australiasian region. His results indicated that several changes in atmospheric circulation have occurred over the region up to 1975:

1) Pressures had become higher south of 40º South.

2) Less westerly flows between 30º S and 45º S.

3) More northeasterlies or less southwesterlies flow across New Zealand.

Salinger (1980a, 1980b) examined the relationship of rainfall and temperature to Trenberth's (1976) indices over the New Zealand region. The rainfall results indicated that the dominant patterns of precipitation variation were related to the strength and position of zonal flow over the country. Results suggested that topography may be an important component for strongly localised precipitation anomalies over New Zealand.

Sturman et al (1984) looked at atmospheric circulation of the South Island of New Zealand for the 1961-1980 period. Their results indicated the dominance of anticyclonic circulation with westerly airflows being clearly evident. Anticyclonic southwesterly was found to be the most important type in all seasons. Their time series of circulation indices showed important variations over the period when smoothed (Figure 6.1).

6.3 METHODOLOGY

This section is divided into three subsections:

1) A description of the classification scheme used for daily weather charts.

2) Use of moving trends.

3) The types of statistical analysis used.

6.3.1 CATEGORISATION OF DAILY WEATHER CHARTS

The technique used in this thesis to categorise the daily synoptic flows follows the lines used by Sturman et al (1984). Their subjective technique was used in looking at daily sea level atmospheric circulation over the South Island, New Zealand. The 1961

FIGURE 6.1 STURMAN'S et al (1984) TIME SERIES OF 4 CIRCULATION INDICES, 1961- 1980, USING 3 AND 12 TERM MOVING AVERAGES

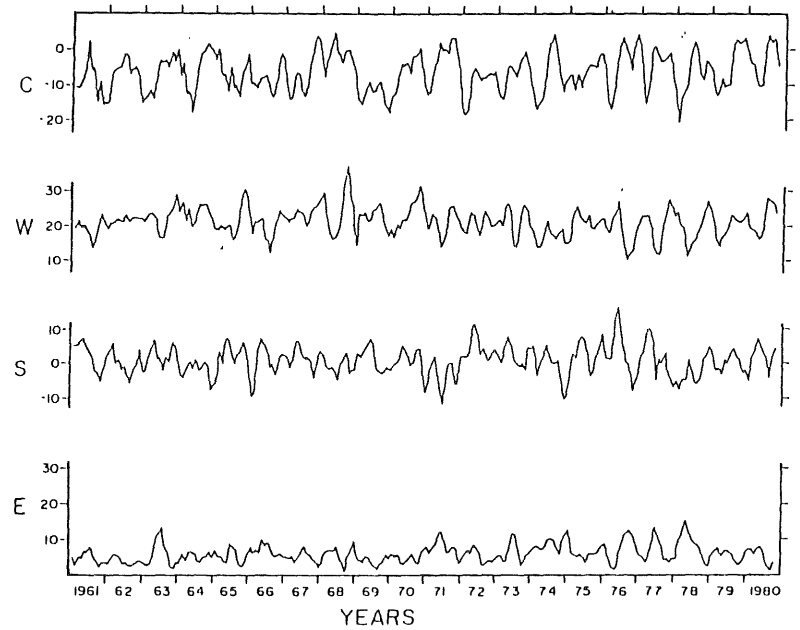


Fig. 3: Time series of the four circulation indices, 1961-1980, smoothed using a 3 term moving average (labels as in Figure 2).

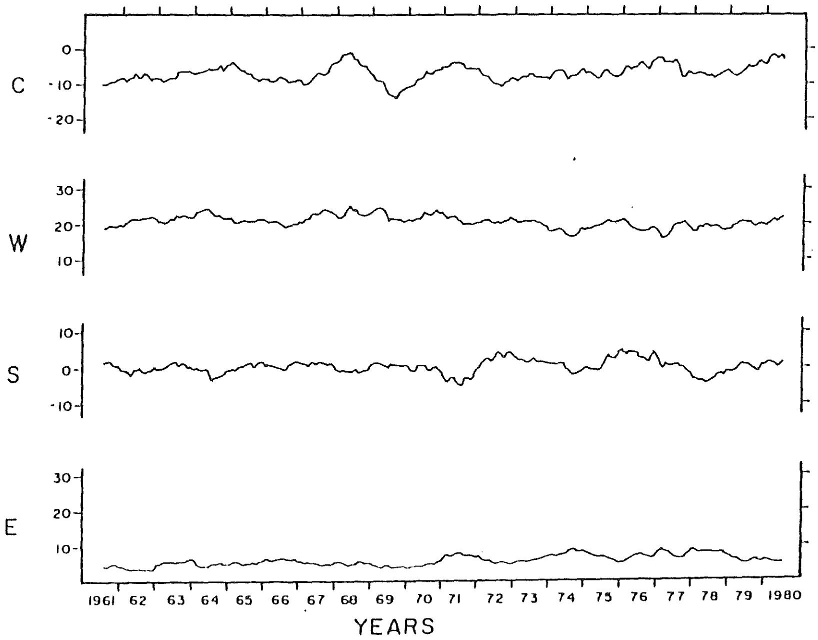


Fig. 4: Time series of the four circulation indices, 1961-1980, smoothed using a 12 term moving average (labels as in Figure 2).

SOURCE: STURMAN et al (1984)

to 1980 period had already been classified by Sturman et al (1984) in their study of atmospheric circulation over the South Island, New Zealand. This author classified the 1929-1940, 1957-1960, and 1981-1985 period using the New Zealand Meteorological Service's daily weather charts. 0900 to 1500 hours (local time) daily weather were used as the 1200 hours (local time) daily weather were not always available. The 1941-1956 period had been classified by Mr van der Assum of the Meteorological Service using a slightly different scheme. His scheme only used cyclonic and anticyclonic categories while Sturman's classification scheme had an additional unspecified category (table 6.1). This caused problems in the compatibility of the cyclonic flow indices between the two schemes. This problem is discussed later on.

Withvarious people classiflying the daily weather charts, differents in interpretation of airflows could have occurred. However comparisons of results, apart from the cyclonic indices, indicated no real deviation.

Once the daily weather charts had been categorised and coded, daily types were used to calulate the monthly circulation indices (Table 6.2) following Sturman et al (1984). Five circulation indices were used (Table 6.2) in this study in an attempt to improve the representation of southerly and northerly flow.

TABLE 6.1 THE TWO CLASSIFICATION SCHEMES USED FOR CATEGORISING DAILY SYNOPTIC CHARTS AT SEA LEVEL

STURMAN'S CLASSIFICATION SCHEME

	Nth	NE	E	SE	Sth	SW	W	NW	ND*	TOTAL
ANTICYCLONIC CYCLONIC UNSPECIFIED										
TOTAL										

VAN DER ASSUM'S CLASSIFICATION SCHEME

	Nth	NE	E	SE	Sth	SW	W	NW	ND*	TOTAL
ANTICYCLONIC CYCLONIC										
TOTAL										

*Non Directional

TABLE 6.2 DAILY INDEX VALUES USED TO CALCULATE MONTHLY CIRCULATION INDICES

CYCLONICITY INDEX	Non-directional anticyclonic	-2
	Directional anticyclonic	-1
	All unspecified	0
	Directional cyclonic	1
	Non-directional cyclonic	2
WESTERLY INDEX	Westerly	2
	Northwesterly or southwesterly	1
	All other classifications	0
SOUTHERLY INDEX	Southerly	2
	Southwesterly or southeasterly	1
	All other classifications	0
EASTERLY INDEX	Easterly	2
	Southeasterly or Northeasterly	1
	All other classifications	0
NORTHERLY INDEX	Northerly	2
	Northeasterly or northwesterly	1
	All other classifications	0

(Sturman 1984)

6.3.2 MOVING TRENDS

This chapter looks at the significance of synoptic flow patterns on rainfall and temperature trends. This was to determine if changes in synoptic flow patterns lead to changes in rainfall and temperature trends. Ten and thirty year moving trends were used for the five circulation indices to determine changes in synoptic flow patterns, and to be compatiable with the rainfall and temperature trends. Yearly values were also used to determine the significance of synoptic flow patterns on rainfall and temperature variation. Seasonal and annual synoptic trends were compared to rainfall and temperature trends. For monthly trend comparisons, the coldest (July) and warmest (January) months were used for temperature while the driest (February) and wettest (July) months were used for rainfall.

6.3.3 STATISTICAL ANALYSIS

Various statistical techniques were used for analysis of synoptic flow influences on rainfall and temperature trends, and correction of cyclonic flow indices for the 1941-1956 period.

Significance tests were conducted on rainfall and temperature trends. For this both rainfall and temperature values were divided into three categories using the following method:

1) BELOW NORMAL VALUES: More than one S.D. below the mean rainfall/temperature value.

2) NORMAL VALUES: Within 1 S.D. of the mean rainfall/ temperature value.

3) ABOVE NORMAL VALUES: More than 1 S.D. above the mean rainfall/temperature value.

Student's " t " test were conducted between below normal periods and normal periods; and between normal periods and above normal periods. Critical values value chosen was the 1% significance level. The tests were to determine if periods of average rainfall and temperature values were significantly different from periods of below and above normal rainfall and temperature values.

It was considered necessary to make corrections to the cyclonicity index values for the period 1941 to 1956. This was because the values were found to be too strongly positive (cyclonic) in comparison to the other periods. Van der Assum's classification scheme was used during this period. The 1961-1980 period was chosen as the period for correlating the two cyclonic flow indices. Each of the 12 months were correlated separately. Linear regression equations were used to obtain the new monthly cyclonic flow values for the 1941-1956 period. Significance tests (1961-1980 period) were conducted to see if the two classification schemes were significantly different in their cyclonic flow values.

Once the correction procedure had been conducted, multiple regression analysis was used to comparing the five synoptic flow indices against rainfall and temperature values. This analysis was carried out at three scales:

1) Yearly values.

2) 10 year trends

3) 30 year trends

Yearly values were used to determine which synoptic flow patterns were having a significant influence on rainfall and temperature variations. The 10 and 30 year trends were used to determine the influence of changes in synoptic patterns on rainfall and temperature trends.

The Macintosh "*Statsoft* " package was used for the regression analysis providing R and R^2 values with F test to determine the significance of these correlations. Beta and B values were given for each of the five independent synoptic flow indices with "t" tests to determine their significance. The regression analysis determines which independent variables have the most significant influence on the dependent variable.

6.4 COMPARISON OF NORMAL PERIODS WITH ADNORMAL PERIODS (RAINFALL/TEMPERATURE)

Student's " t " test were used to determine if normal rainfall and temperature periods, on a 10 and 30 year trend scale, were significantly different from above and below normal periods. Seasonal and annual trends for Christchurch and Akaroa (rainfall only) were used in these tests. Periods with less than six observations were not considered.

6.4.1 RAINFALL

Results showed that both below normal and above normal rainfall periods were significantly different from normal rainfall periods at the 1% level. This was true for both of the tested stations for the 10 and 30 year trend scales. Table 6.3 shows the statistical results for the 10 year scale. The 30 year scale showed very similar results.

6.4.2 TEMPERATURE

Only Christchurch's maximum, minimum, and mean temperatures trends were tested in this analysis. It would be expected that Onawe and Lincoln would show similar results. As in the rainfall tests, all statistical results were found to be significant for the 10 and 30 year trend scales. The above and below normal temperature periods were found to be significantly different to normal tamperature periods. However non-climatic elements like sheltering and urban heat emission may well be influencing the

TABLE 6.3 RESULTS OF STUDENT'S "t" TEST TO DETERMINE IF ABOVE AND BELOW NORMAL RAINFALL PERIODS ARE SISNIFICANTLY DIFFERENT FROM NORMAL RAINFALL PERIODS

Akaroa and Christchurch stations were used in this analysis as representative of the study area.

	D.F.	"t" VALUE*	COMPARISON TEST	
			Below normal to normal periods	Above normal tc normal periods
SUMMER				
Christchurch	106	-10.0	√	
	92	-9.2		√
Akaroa	63	-12.6	√	
	69	-10.9		√
AUTUMN				
Christchurch	103	-15.4	√	
	96	-10.7		√
Akaroa	67	-7.2	√	
	71	-12.7		√
WINTER				
Christchurch	97	-11.0	√	
	97	-11.6		√
Akaroa	64	-8.3	√	
	64	-9.6		√
SPRING				
Christchurch	97	-17.3	√	
	61	-3.8		√
Akaroa	70	-14.9	√	
	67	-15.8		√
ANNUAL				
Christchurch	97	-12.0	√	
	97	-15.8		√
Akaroa				

* All results significant at the 1% level

TABLE 6.4 RESULTS OF STUDENT'S "t" TEST TO DETERMINE IF ABOVE AND BELOW NORMAL TEMPERATURE PERIODS ARE SISNIFICANTLY DIFFERENT FROM NORMAL TEMPERATURE PERIODS

Christchurch station was used for this analysis

	D.F.	"t" VALUE*	COMPARISON TEST: Below normal to normal periods	COMPARISON TEST: Above normal tc normal periods
SUMMER				
Maximum temp	54	-5.6	√	
	56	-10.3		√
Minimum temp	65	-11.2		√
Mean temp	51	-7.5	√	
	61	-8.9		√
AUTUMN				
Maximum temp	58	-5.9	√	
	63	-10.2		√
Minimum temp	56	-7.9	√	
	60	-13.5		√
Mean temp	56	-6.4	√	
	60	-11.7		√
WINTER				
Maximum temp	70	-13.6	√	
Minimum temp	61	-6.7	√	
	57	-13.2		√
Mean temp	58	-15.0	√	
	56	-7.5		√

Table 6.4 continue

Spring				
Max temp	57	-12.7	√	
	58	-8.8		√
Minimum temp	67	-11.1	√	
Mean temp	65	-8.5	√	
	64	-9.4		√
ANNUAL				
Maximum temp	54	-9.0	√	
	54	-7.9		√
Minimum temp	62	-10.0	√	
	60	-9.7		√
Mean temp	65	-6.8	√	
	62	-5.8		√

*All results significant at the 1% level results especially the above normal temperature. Table 6.4 shows the statistical results for the 10 year trends. The 30 year trends showed similar results.

6.5 SYNOPTIC FLOW PATTERNS AND TRENDS

684 months or 57 years of daily weather charts were classified into atmospheric circulation types using a combination of Sturman (1929-1940, 1957-1985) and van der Assum's (1941-1956) schemes. Seasonal and annual flow patterns and trends will be presented in this section as well as the wettest (July), driest (February), warmest (January), and coldest (July) months of the year.

6.5.1 VARIATION IN SYNOPTIC FLOW PATTERNS OVER A YEAR

Figure 6.2 shows the monthly circulation over the South Island for the five circulation types. The results clearly show seasonal variations.

Cyclonic conditions are stronger in winter and in November while anticyclonic conditions prevail in February. Westerlies reach their maximum strenght in spring and are less frequent in summer.

FIGURE 6.2 AVERAGE MONTHLY CIRCULATION INDICES DERIVED FROM THE DAILY SYNOPTIC CIRCULATION, 1929-1985

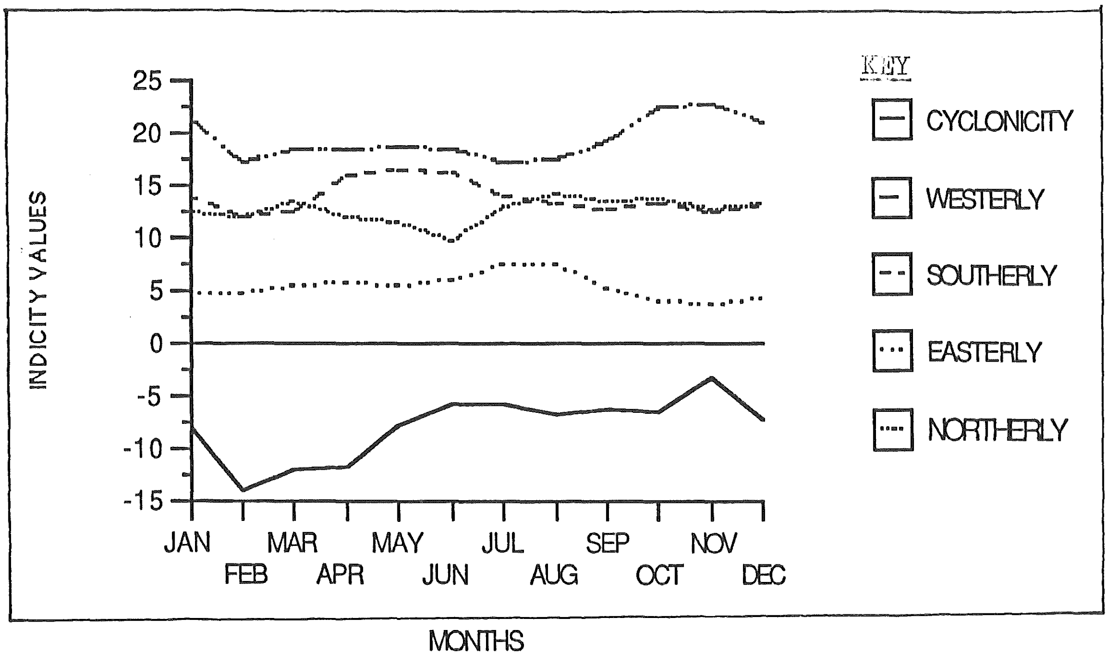
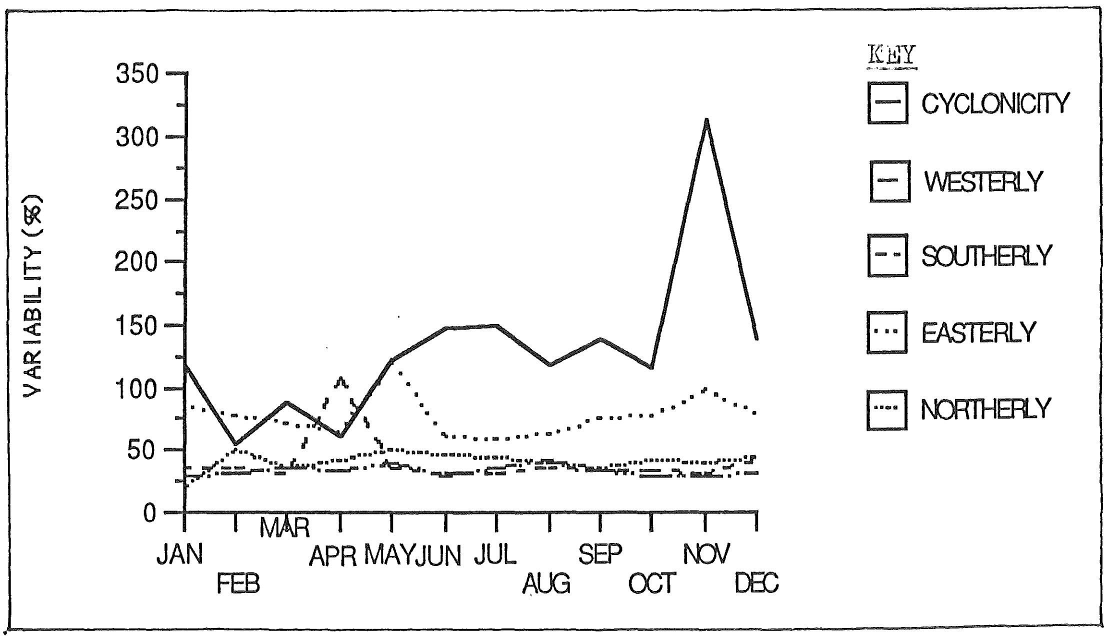


FIGURE 6.3 MONTHLY VARIABILITY (ABS(S.D./MEAN)*100%) OF THE FIVE CIRCULATION INDICES



Southerlies have their minimum in February but are most frequent in May and June. Easterlies reach their maximum in winter but decrease rapidly in spring to reach their minimum in November, a result of the strengthening westerlies in spring. Variations in Northerly circulations are quite small but do show increased frequency around spring and are less frequent around the beginning of winter. Figure 6.3 shows the variability (abs(S.D./mean) * 100%) of the five circulation types.

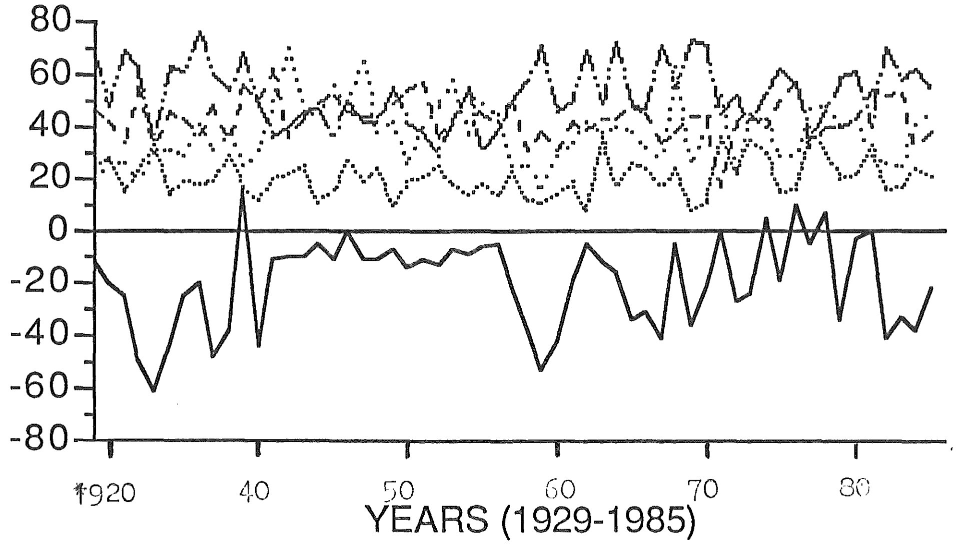
6.5.2 RECORD PERIOD (1929-1985)

All three (January, February, July) showed a significant increase in cyclonic activity from the late 1930's to the mid 1950's. This coincides with the wet period experienced in the study area during the 1940's and 1950's. The increase was more noticeable in February than in January and July. The increase in cyclonic flows in the mid 1970's in January and July also coincided with the wet years of the 1974-1980 period. Easterlies also increased during this period. The 1930's were quite anticyclonic in which the study area experienced dry conditions (1929-1935). February has shown a consistent increase in anticyclonic conditions since the 1950's.

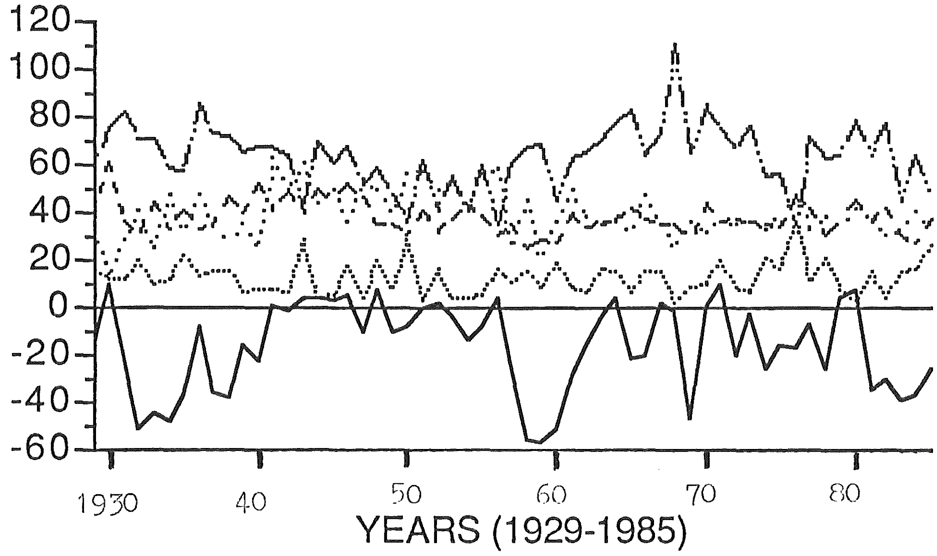
Figure 6.4 shows the seasonal circulation flows. All clearly indicate the cyclonic flow during the 1940's to the 1950', and in the

FIGURE 6.4 TIME SERIES OF THE FIVE CIRCULATION INDICES, 1929-1985, ON A SEASONAL BASIS

WINTER CIRCULATION



SPRING CIRCULATION



1970's in the winter and spring season. Both of these periods coincided with wet spells in the study area. Conversely the dominance of anticyclonic conditions in the 1930's, 1960's and 1980's conicided with drier periods. Most seasons showed a marked decrease of northerly airflows in the 1930's which coincided with the cool period experienced then. All of the seasons showed a decrease in westerly flows during the 1940's and 50's, coinciding with increased cyclonic flows. In terms of spring temperatures, the increase in westerlies (1960's, early 1970's) coincides with warmer springs while decrease in westerlies (1930 - 40's) coincides with cooler springs. Spring and summer have seen a reduction in southerly airflows since 1955. Winter has seen a increase in easterlies since the 1970's coinciding with increased cyclonic flows resulting in the wet winter spell of 1974 to 1981 in the study area.

6.5.3 TEN YEAR TRENDS

Figure 6.5 shows the seasonal airflow trends of the five circulation types. Obvious trends are clearly indicated in each of the five circulation types. The following is a desription of trends with some reference to rainfall and temperature trends:

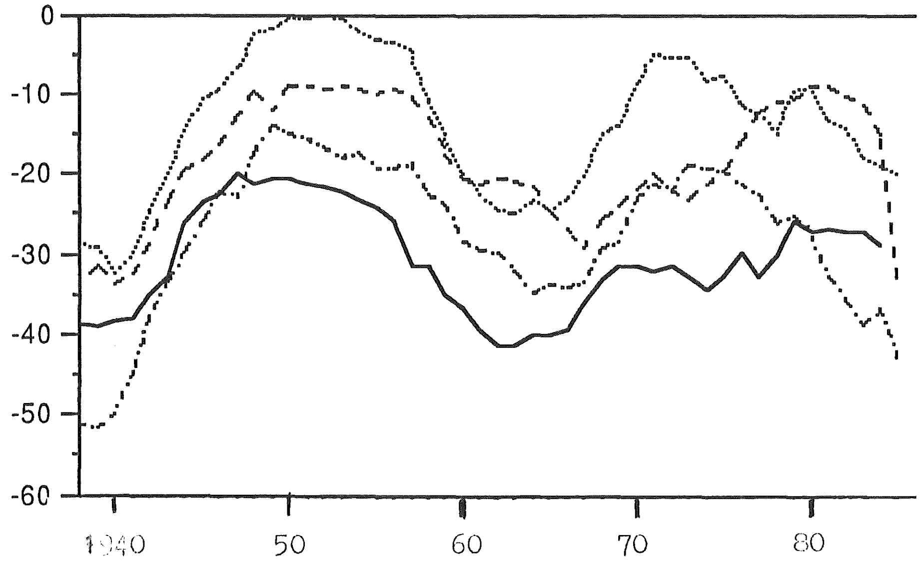
1) The 1930's was a period of strong anticyclonic conditions. Westerly flows were also strong as well. This indicates a period of strong zonal flow over New Zealand with anticyclonic west to

FIGURE 6.5 TEN YEAR MOVING TRENDS FOR THE FIVE CIRCULATION INDICES ON A SEASONAL BASIS

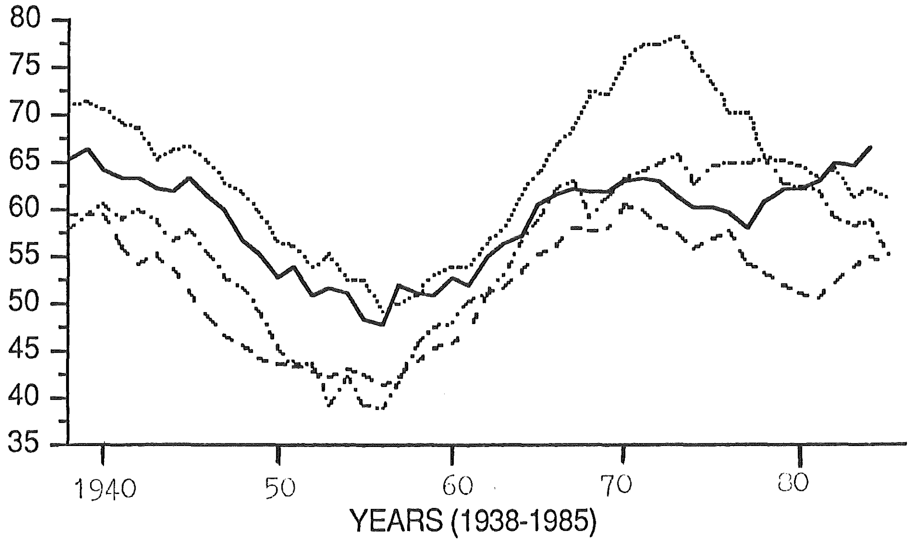
KEY

SUMMER — WINTER — AUTUMN — SPRING

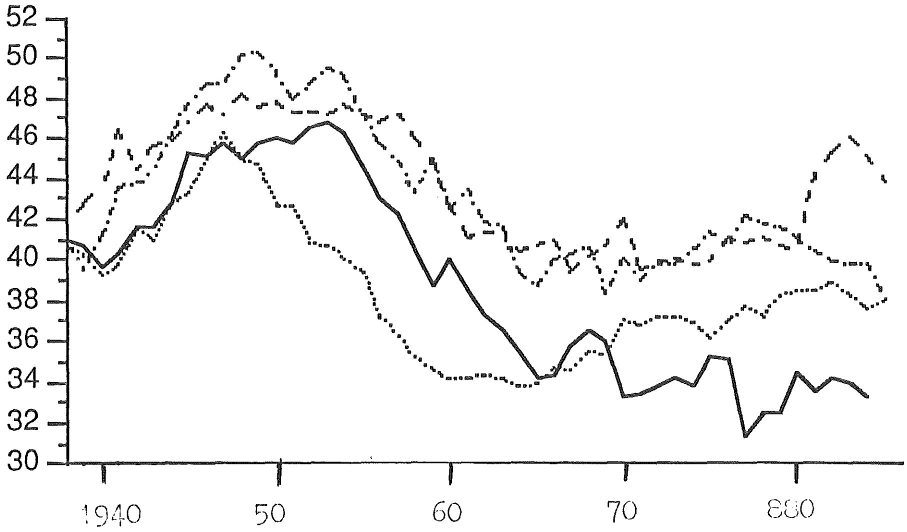
SEASONAL CYCLONIC CIRCULATIONS



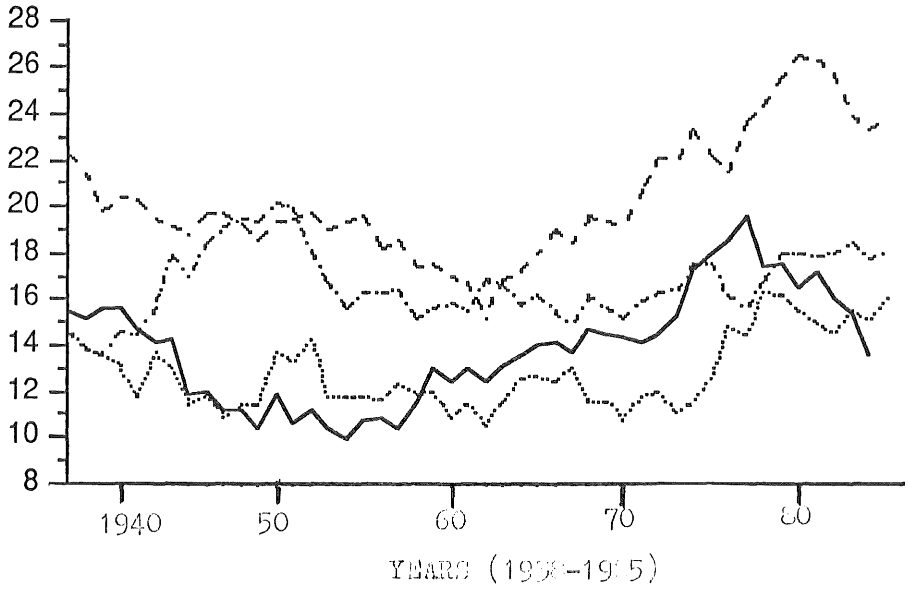
SEASONAL WESTERLY CIRCULATIONS



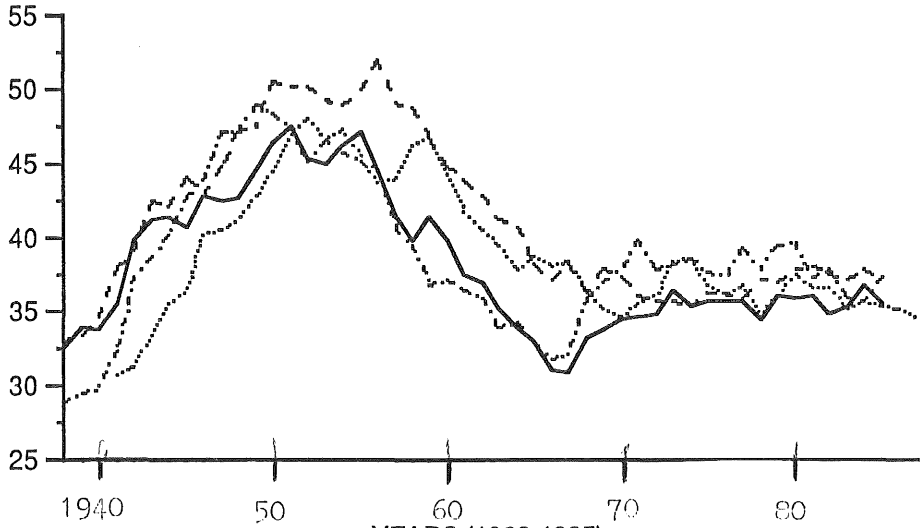
SEASONAL SOUTHERLY CIRCULATIONS



SEASONAL EASTERLY CIRCULATIONS



SE^a^SONAL NORTHERLY CIRCULATIONS



YEARS (1938-1985)

southwesterly conditions being dominant. Notice the relatively low incidence of northerly airflows in this period in comparison to southerly airflows. This was a cool period for New Zealand as well as being dry (1929-1935) in the study area.

2) The 1940's - 50's was a period of increased cyclonic flow which coincided with the wet period in the study area. At the samr time westerly flows decrease in strenght while northerlies and southerlies increased in strength. This probably indicates two factors: a) A more northerly position of polar low pressure systems over the New Zealand region and possibly more frequent development of cyclonic conditions in the Tasman Sea area. This would indicate that anticyclones may have had a more northerly track during this period. Decreasing trends in easterlies suggest this as easterly flows occur on the northern side of anticyclones.

b) Decrease in zonal flows (westerlies) with increased meridional (north - south), possibly a result of increased cyclonic conditions. This would indicate a weakening of the mid-latitude westerlies over the New Zealand region. This would result in a slower progression of weather systems over New Zealand leading to increased rainfall over the study area when cyclonic systems move more slowly over New Zealand.

Autumn was the only season which had a marked increase in easterly flows which coincided with increased cyclonic conditions. This may indicate a frequent passage of cyclonic systems from the north, such as decaying tropical cyclones.

3) An increase in anticyclonic conditions occurred in the 1960's with a corresponding increase in westerly flows, and a marked decrease in northerly and southerly airflows. This probably indicates the strengthening of the westerlies over New Zealand coinciding with a more southerly position of anticyclones over New Zealand. Polar low systems would also be pushed further south in the New Zealand region. The high incidence of westerly flows in spring during the 1960's coincided with the warmest springs recorded in the study since records began.

4) The 1970's saw a return to more cyclonic flow conditions especially in spring and winter. However two significant conditions occurred with the more frequent cyclonic flows: a) 1969 to 1973 was a period of strong westely flows indicating that many of the low pressure systems were passing south of New Zealand. This would relate to the dry conditions experienced in Canterbury at this time.

b) The 1974 to 1980 period saw a increase in easterlies with a corresponding decrease in westerly airflows. This suggests a more frequent passage of cyclonic activity from the Tasman Sea and possibly secondary development of frontal systems over New Zealand. This was a wet period for the study area.

5) The 1980's have seen an increased in anticyclonic flows resulting in drier conditions , especially summer. Easterly flows have still remained relatively high.

Other major points to note are the higher frquency of easterly flows in winter compared to the other seasons. Northerly flows have remained stable since the 1960's. At the same time the southerly flow has gradually decreased in autumn and summer, remained stable in winter until 1980, and gradually increased in spring. Winter and spring experience more cyclonic flow conditions while simmer and autumn experience more anticyclonic conditions.

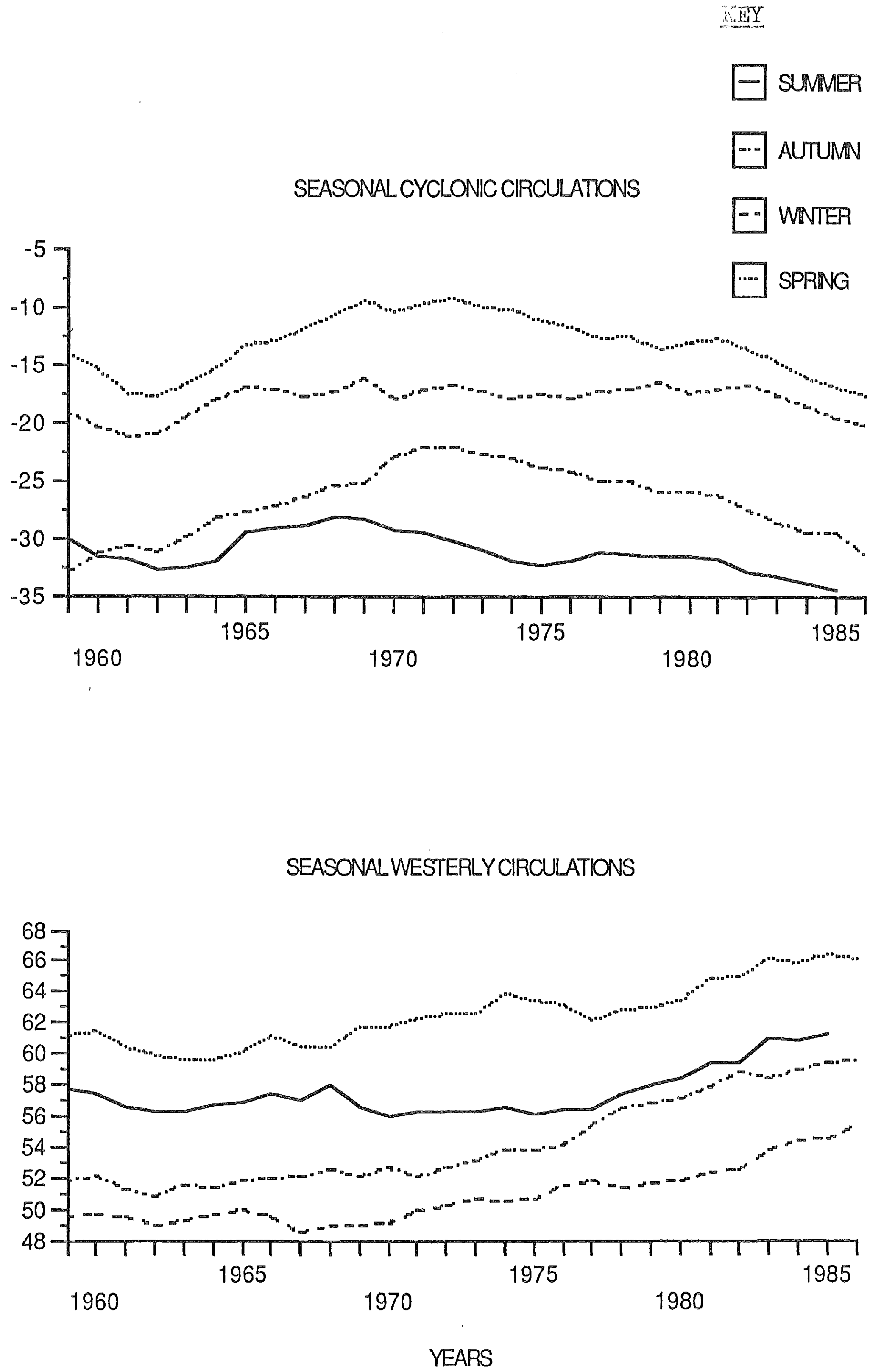
Figure 6.6 shows January, February, July, and annual circulation flows. The months show similar trends to their respective season while annual trends summaries the seasonal trends.

6.5.4 THIRTY YEAR TRENDS

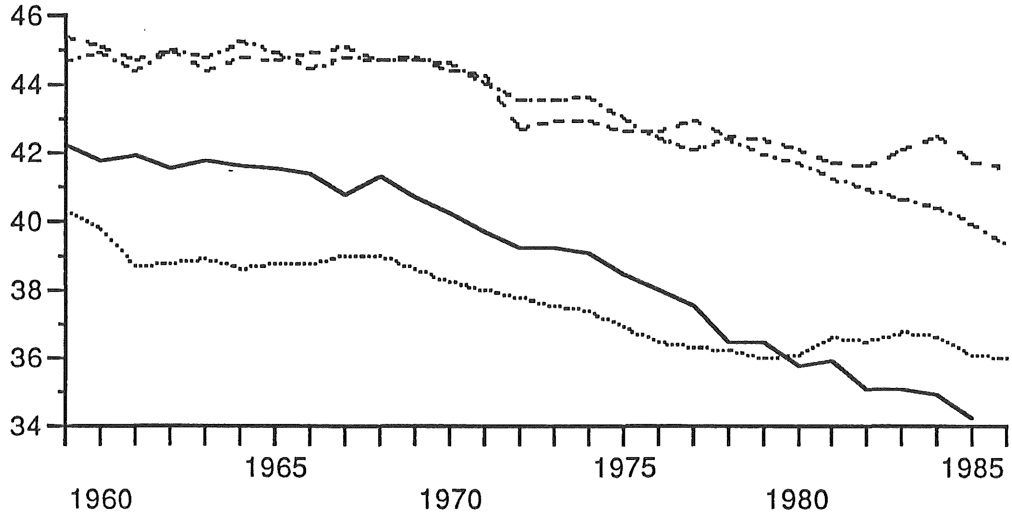
The three chosen months showed a slight increase in easterlies since 1970 and a progressive increase in westerlies since 1958. There has been a decline in northerlies since 1970. January and February have shown noticeable increase in anticyclonic conditions since 1958

Figure 6.7 shows the seasonal trends of the five circulation

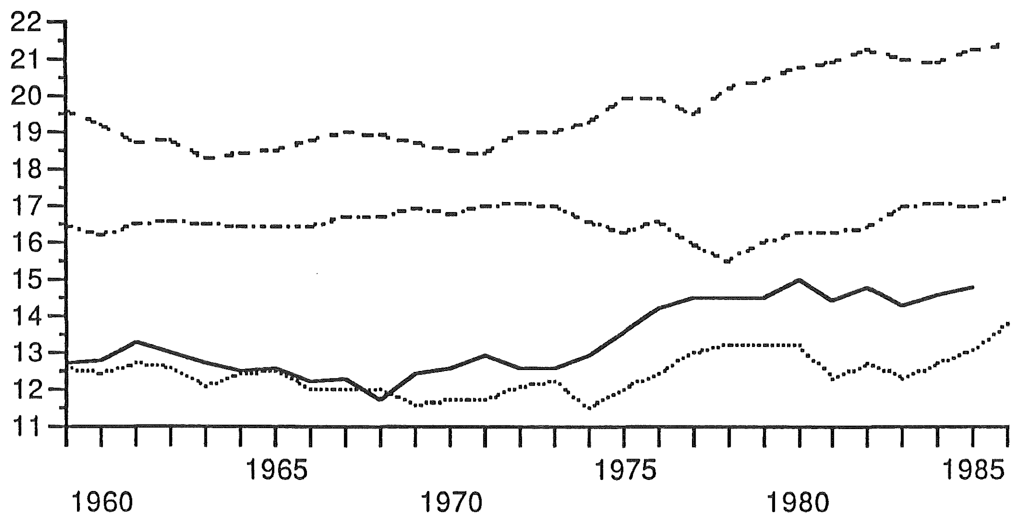
FIGURE 6.6 THIRTY YEAR MOVING TRENDS FOR THE FIVE CIRCULATION INDICES ON A SEASONAL BASIS

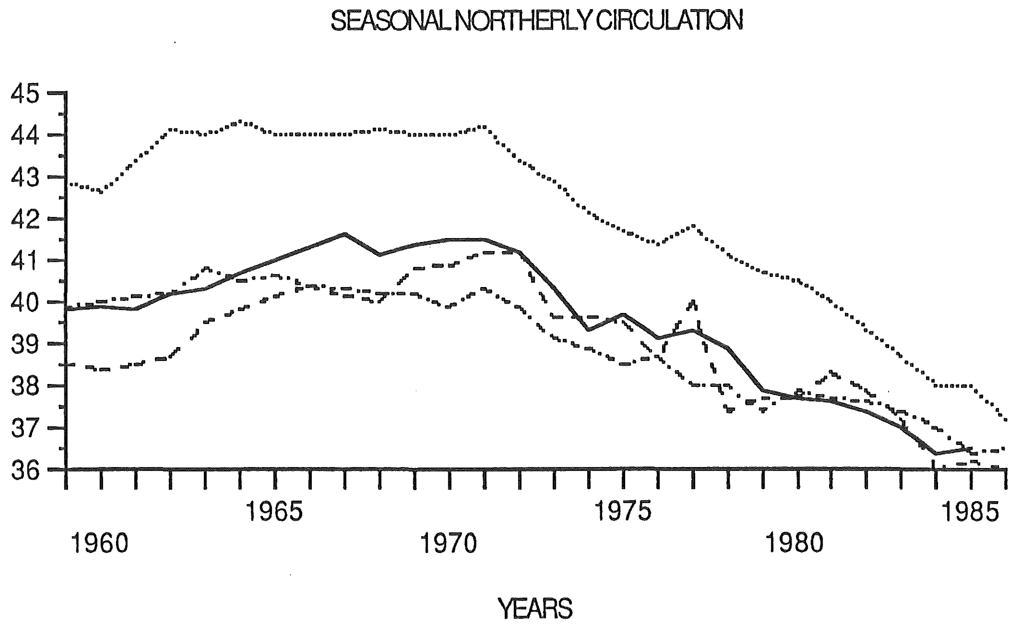


SEASONAL SOUTHERLY CIRCULATIONS



SEASONAL EASTERLY CIRULATION




SEASONAL NORTHERLY CIRCULATION
45
44
43
42
41
40
39
38
37
36
1965
1975
1985
1960
1970
1980
YEARS

types. The following is a list of the significant trends:

1) Progressive decrease in cyclonic flows since 1970 in all seasons. Summer and autumn are more strongly influenced by anticyclonic flows than in winter and spring.

2) Progressive increase in westerlies since the early 1960's in all seasons. This probably reflects the increasing strength of zonal flows over New Zealand.

3) Steady decrease in southerly airflows since 1958 especially in summer and autumn. This suggests a decrease in meridional flow over New Zealand.

4) Stable northerly flow until about 1970, then a rapid decrease in all seasons. The rapid decrease in northerly flows since 1970 probably relates to increasing anticyclonic conditions over New Zealand.

5) Increase in easterly flows since 1970. This may reflect Trenberth's conclusion that more anticyclones, since 1940, occur east of New Zealand and less in the Australia and the Tasman Sea area. Several studies have suggested this area to be a preferred area for blocking anticyclones. This may account for the decrease in southerly and northerly airflows over the South Island. It may also be possible that cyclonic activity from the Tasman Sea has become the more dominant than depressions from the south. Figure 6.8 shows the annual trends which is a summary of the seasonal trends.

6.5 MULTIPLE REGRESSION ANALYSIS

This section presents the results of the multi-regression analysis comparing the significance of synoptic flow patterns on rainfall and temperature. Three scales were used in this analysis:

1) Monthly (January, February, July), seasonal, and annual variation of synoptic flow patterns on rainfall and temperature.

2) The significance of changes in synoptic flow patterns on rainfall and temperature trends using 10 year moving trends.

3) The above but using a 30 year moving trends.

Rainfall and temperature results will be discussed separately. Results of the multiple analysis will be presented for the four seasons.

6.6.1 RAINFALL

On the monthly to annual scale the corelation ranger from 0.39 (Autumn) to 0.60 (July). The 10 and 30 year trends showed very strong correlations between changes in synoptic flow patterns and rainfall trends (Table 6.5). The results indicate that on a monthly to annual scale, other factors beside synoptic flow patterns are important as well. An example is the speed, directional movement, and strength of the synoptic feature, such as a low pressure system over the New Zealand region. However, on a longer scale such as the 10 and 30 year scale, changes in synoptic flow patterns are the dominant factor influencing changes in rainfall trends (Appendix 2).

Overall the three time scales used showed a common relatioship between rainfall and circulation types. Cyclonicity, easterly, and southerly consistenly showed positive relationship with rainfall. An increase frequency in one or more of these circulation types would lead to increase rainfall totals/ trends. Northerly flow tended to have a negative relationship with rainfall.

6.6.2 TEMPERATURE

Temperature shows similar results to the rainfall analysis. The monthly to annual temperatures have moderately strong correlations. However, on the 10 and 30 year moving trend scale, temperature trends are very strongly correlated to changes in synoptic flow patterns (Appendix 3). The 30 year trend shows the strongest relationship between synoptic flow trend and temperature trend. Maximum temperature, particularly on the monthly to annual scale, has the strongest relationship with the five circulation types while minimum temperature shows the weakest relationship. This indicate that maximum temperature is more sensitive to fluctuation and changes in synoptic flow patterns than minimum temperature is. A summary of the corrleation is :

1) Cyclonic circulation - Positive relationship with winter and

spring temperature, and negative tendency in summer.

2) Westerly circulation - Positive relationship with winter and autumn temperatures, but negative with spring and summer.

3) Southerly circulation - Negative relationship with temperature in all seasons.

4) Easterly circulation - negative relationship with maximum and mean temperature but positive with minimum temperature.

5) Northerly circulation - negative relatioship with temperature in the colder months.

It must be remembered that a combination of changes in circulation types ultimately influence temperature trends over the study area.

6.7 DISCUSSION

This section discusses the significance of the results desribed in the previous section. Temperature and rainfall will be discussed separately. The significance of the circulation patterns will be examined at three levels:

1) The record period (1929-1985) - To examine the which circulation patterns have a sinificant influence on rainfall and temperature variation on a monthly (January, February, July),

seasonal and annual scale.

2) Ten year moving trends - Discussing the significance of changes in synoptic flow patterns on rainfall and temperature trends.

3) Thirty year moving trends - Same as above.

The eight representative stations are used for the rainfall analysis while Christchurch, Lincoln, and Onawe are used in the temperature analysis.

6.7.1 RAINFALL

February

February is the driest month of the year when anticyclonic conditions prevail. All three time scales indicated that cyclonic circulation is the main factor in increased rainfall, and to a lesser extent, easterly circulation. Their significance on rainfall trend is least on the 30 year moving trend due to the shortness of the total record. Westerly circulation is the significant factor in decreased February rainfall, particularly at the 10 and 30 year moving trend scale. To some extent northerlies also reduces rainfall. The 1940's and 50's was a wet spell for February because of increased cyclonic activity with a corresponding decrease in westerly circulation. However the drier conditions of the 1970's and 80's is a reverse of the above conditions.

The coefficients for the 30 year moving trends were not as significant in comparison to the other two time scales.

July

July is dominantly the wettest month of the when cyclonic activity and easterly flows are more frequent. Wet July's or wet spells in July occur when cyclonic activity are more frequent in combination with easterly and or, southerly circulations. A combination of cyclonic northeasterly to soutwesterly would produce significant precipitation over the study area. This occurs when depressions are situated to the east of Canterbury, or over the North Island. The present wet spell has seen this situations occur fequently and is evident in the circulation graphs with increased cyclonic activity and easterly flows.

Dry July's and dry spells occur when northerly circulations are more frequent than usual as happen during the 1950's and early 1970's.

The Four Seasons

The four seasons will be discussed separately.

Summer

Wet summers occur when cyclonic activity is more frequent than usual. However wet summer spells occur southerly and or, easterly circulations are more frequent. This occurred in the 1940's and 50's when southerly circulations were more frequent. The dry spell of the late 1960's and 70's was the result of rapid decrease in southerly circulation since the late 1950's.

Autumn

On a seasonal basis none of the five circulation types had a significant impact on autumn rainfall. This suggests that a combination of the above circulation have resulted in wet or dry autumns. It may also suggest that atmospheric varies quite marketly through out autumn (Figure 6.1). The other two time scales indicate that cyclonic circulation as being the dominant factor for increased rainfall trends. To some extent southerly (10 year miving trend) are also important. The wet spell of the late 1940's to early 1950's was a of this. However the wet spell of the 1960's was related to the decrease in northerly circulation which has a negative impact on rainfall trends.

Winter

All three scales show consistent results. The 10 year trend shows the strongest results. Wet winters occur when cyclonic activity in combination with higher frequency of southerly and or, easterly circulations. Significant rainfall would occur when cyclonic southwesterly to northeasterly flows over the study area. For rainfall trends the following combination would result in wet winter periods:

1) Increased cyclonic activity.

2) Increased frequency of one or more of the following circulations; easterly, southerly, or westerly (10 year trend only).

3) Decrease in northerly circulations.

The present wet spell has been the result of increased cyclonic activity in combination with increased southerly and easterly circulations.

Spring

Southerly and easterly circulation are the significant factors that result in wet springs or wet spells in spring such as the 1940's and 50's. Spring is the only period that has a significant negative relationship with cyclonic index. This suggests that most of the increased cyclonic activity pass south of the study area resulting in cyclonic westerly flows over the South Island. On the 10 year moving trend scale the dry spell of the 1960's and early 70's was mainly the result of increased westerly circulation and a decrease in southerly circulation. For the 30 year trend the present dry spell can be related to decrease in southerly circulation.

Annual

Annual rainfall is an overall summary of the seasonal analysis.

Wet years occur when southerly and or, easterly circulations occur frequently through out the year. Southerly and easterly circulations are the main rain bearing winds in the study area. In terms of of annual rainfall trends southerly and easterly circulations are the dominant factors. The wet spell of the 1940's and 50's was the result of high frequency of southerly circulation while the wet spell of the late 1970's was due to increased easterly circulations.

6.7.2 TEMPERATURE

Record period (1929-1985)

The relationship between temperature and synoptic flow variations is examined on a year to year basis using monthly, seasonal, and annual scale.

On all scales (monthly, seasonal, annual) southerly circulation is the most significant factor producing cooler temperatures over the study area. Easterly circulation also tends to bring cooler temperatures, particularly in spring. However warmer temperatures are associated with easterlies in autumn as these airflows are turbulent and cloudy. In summer, and January northerly circulation has a positive relationship with temperature. This is particularly so for maximum temperature. This indicates that these airflows experience adiabatic warming after crossing the Southern Alps and are associated with significant warm advection. However it is the westerly circulations in autumn and winter that are associated with warmer temperatures. July also indicates this. This is also associated with adiabatic warming after crossing the Southern Alps. Colder temperatures occur under southerly and easterly flows which do not experience adiabatic warming. On an annual basis southerly circulation is the most significant factor having a negative relationship with temperature while easterly circulation has a lesser but cooling impact on maximum temperature.

Ten year moving trends

This section examines the relationship between changes in synoptic flow patterns and temperature trends. As shown in the record period southerly flow is the most significant factor that influences temperature trends in the study area, having a negative impact. Increased easterly circulation also tends to have a negative impact on maximum temperatures.

Summer is the only season in which temperature does not has a significant positive relationship with circulation. However the other three seasons show a positive relationship between temperature trends and circulation but it varies between the seasons. Increased cyclonic activity has a positive impact on temperature in winter and spring while increased westerly circulations in autumn and winter result in warmer temperature trends but cooler temperatures in spring.

The cool period of the 1930's and 40's was the result of a higher frequency of anticyclonic in combination with a higher frequency of westerly and southerly circulation. This indicates that anticyclonic west to southwesterly conditions were quite dominant through-out this period. The warming trend was initiated by the increase in cyclonic activity during the late 1940's to early 1950's but was stunted by the higher frequency of southerly circulations and to some extent northerly circulations. The rapid warming phase from the mid 1950's to 60's was the result of the rapid decrease in southerly circulations (Figure 6.5) and an increase in westerly circulations. Temperatures have somewhat stabilised since the 1970's which coincides with stabilization of southerly circulation trends. However the recent declining temperature trend in spring has been the result of increased southerly circulation and a decrease in westerly circulation.

On a annual basis southerly and westerly circulations result in cooler temperature trends indicating that southwesterly airflows are a significant factor. An increase in cyclonic and easterly circulations result in rising temperature trends.

<u>Thirty year moving trends</u>

The longer term relationship between synoptic flow trends and temperature trends is examined. Their relationship is somewhat similar to the 10 year moving trends but are less significant due to the shortness of the total record. However the noticeable exception is the summer season which shows very significant negative relationship with southerly and easterly flows and to a lesser extent westerly circulations.

In the 30 year trend series, the recent warming temperature trends have been due to the rapid decrease in southerly flow. The R and R^2 values are very high indicating the very significant impact synoptic flow trends has on longer term temperature trends.

6.8 CONCLUSION

The aim of this chapter was to determine if changes in synoptic patterns have a significant impact on rainfall and temperature trends in the study area. Also studied was the influence of synoptic patterns on monthly (January, February, July), seasonal, and annual rainfall and temperature patterns. Multiple regression analysis was used to examine these relatioships.

Before the multiple regression analysis was conducted, it was determined that normal rainfall/temperature periods were significantly different from periods experiencing above or below normal rainfall and temperature.

The multiple regression analysis showed that synoptic flow patterns/trends have a significant impact on rainfall and temperature variations and trends. Temperature tended to show a higher correlation with the five circulation types than rainfall indicating that synoptic flow patterns/trends has a more significant control on temperature than rainfall in the study area. Very high explained variances were obtained in the 10 and 30 year scale analysis indicating the significance that changes in synoptic flow trends has on rainfall and temperature trends. R and R^2 values obtained for monthly, seasonal, and annual scale were much lower than those obtained on the 10 and 30 year scale. This indicated that other factors also contribute to rainfall and temperature variations at these scales.

Most rainfall trends at the various time scales used tended to have a positive relationship with cycloncity, southerly, and easterly circulations while showing a negative relationship with westerly, and to some extent northerly airflows. The wet period of the 1940's and 50's were a reult of increases cyclonic activity and southerly airflows while the wet period of the 1974 to 1980 years was due to increased cyclonic and easterly airflows. There is a possible suggestion that increased meridional flows associated with increased cyclonic acivity results in wet periods while dry spell occur ir stronger zonal flows associated with increase anticyclonic conditions. Some localised patterns did show up in the monthly tc annual rainfall analysis but synoptic flow patterns were obviousl, the most important factor.

Temperature trends tended to vary from season to season. Some seasons showed the opposite relationship with the same circulation type. However all seasons dominantly showed significant negative relatioship with southerlies while most showed positive relationship with increased cyclonic activity. 1930's to early 1940's cool spell was a period of high incidence of anticyclonic conditions with high frequency of west to southerly conditions. The results indicate that the recent warming has been due to a decrease in southerly circulation, the slight increase in easterly circulations, and to some extent the increase in westerly circulation.

CHAPTER SEVEN

SYNOPTIC RAINFALL CLIMATOLOGY OF THE STUDY AREA

7.1 INTRODUCTION

Previous chapters have looked at rainfall and temperature over the study on a medium to long term basis. Chapter 4 gave a discussion of the background climatology of the study area using monthly to annual scales. Chapter 5 discussed the climatic trends of rainfall and temperature using 10 and 30 year moving trends. Chapter 6 examined the relationship of rainfall and temperature over the study with synoptic flow. The emphasis of this chapter is to examine the relationship between rainfall and synoptic flow patterns on a short term scale (daily basis).

Synoptic climatology is concerned with obtaining an insight into local or regional climates by examining the relationship of weather elements to synoptic circulation processes (Barry and Perry, 1973). The basic aim of synoptic climatology is to relate local or regional climates to the circulations. This involves two stages in synoptic climatological studies:

1) The determination of categories of atmospheric circulation type (Sturman's classification scheme).

2) The assessment of weather elements in relation to these categories.

In this chapter the synoptic rainfall climatology of the study area will be examined. Four specific areas will be examined:

1) Determining the dominant rain-bearing winds.

2) The probability of rainfall occurring over the study area under different synoptic flow conditions

3) The average daily rainfall totals over the study area under different synoptic conditions.

4) Three extreme rainfall events over the study area.

Daily rainfall figures for the period 1981 to 1985 were used at approximately 35 stations.

7.2 PREVIOUS RESEARCH IN THE CANTERBURY REGION

Over the last 10 to 15 years, a limited number of projects have examined the rainfall distribution over the Canterbury region. Most of these studies have used rainfall data on a monthly to annual basis.

Very few studies have used daily rainfall figures.

Salinger (1979,1980) has conducted two studies looking at Canterbury rainfall. The first study attempted a regional classification of rainfall response areas using cluster techniques. Annual rainfall was used. Using 30 stations in the Canterbury region Salinger identified three response areas:

1) Alpine spillover - lies between the main divide and eastern foothills.

2) Canterbury - lies from Kaikoura to Lynnford.

3) South Canterbury - south of Lynnford.

In his later study (1980) he examined the correlation between atmospheric circulation and annual precipitaion over New Zealand. Because of the dominance and strenght of the westerly flow he found that Canterbury lay between a zone of strong positive correlation over the southwest of the South Island and negative correlation to the northeast.

Goulter (1982) examined the spatial variation of the wettest month over the Canterbury region. His results indicated that the inland plains and foothills experienced a December maximum while the coastal areas and the northeast experienced a mat maximum. This author has found that the wetter regions of the study area experience a July maximum while the drier regions have a May maximum rainfall.

Sturman (1986) examined the relationship between monthly precipitation and atmospheric circulation over the Canterbury region. The study provided a clear picture of the way atmospheric circulation influences precipitation over the plains. Three zones were found over the Canterbury region where rainfall and atmospheric circulation showed strong positive corralations:

1) Westerlies - the mountain region of Canterbury.

2) Cyclonicity - South Canterbury region, the foothills and intermintane basin areas, and parts of Banks Peninsula.

3) Easterlies - Canterbury Plains, most of Banks Peninsula, and the northeast region of Canterbury.

Trewinnard and Tomlinson (1986) examined the patterns of daily precipitation (1978-1981) in the central Canterbury area to synoptic flows using prinipical component analysis. Their analysis indicated that most of the significant precipitation falls under northeast to southerly airflows under the influence of cyclonic systems. The rainfall distribution was found to vary across Central Canterbury depending on the position of the low pressure system and the direction of airflow. Six synoptic patterns were found to produce significant rainfall over Central Canterbury.

7.3 METHODS

Daily rainfall totals for the period 1981 to 1985 were used i this analysis. The daily rainfall totals were categorised into Sturman's classification scheme (27 synoptic flow situations). Daily rainfall totals were rounded to the nearest millimetre. Only raindays recording greater than 1mm were considered. Approximately 35 stations were used over the study area to determine the following two factors:

1) The probability of rainfall occurring for each of the 27 synoptic flow features.

2) Average daily rainfall totals under the 27 different flow patterns.

For the probability analysis the number of each of the 27 synoptic flow patterns were determined for the 1981-1985 period. The number of raindays occurring on each of the 27 synoptic flow patterns were then obtained. the following formula was used to determine the probability of rainfall occurring on each of the 27 synoptic flow patterns:

$$\text{PROBABILITY OF RAINFALL} = \frac{\text{Number of raindays that occurred}}{\text{Number of days the synoptic flow pattern occurred}}$$

For example 300 days of anticyclonic southwesterly conditions were experienced. Out of those 300 days it rained on 135 at a particular station. Therefore the probability of rainfall occurring under anticyclonic southwesterly conditions is 135/300 = 0.45. This was determined for each of the 35 stations and mapped.

Average daily rainfall totals were determined for each of the 35 stations. The following was used to calculate the average daily rainfall totals for each of the 27 synoptic flows features:

$$\text{AVERAGE RAINFALL TOTALS} = \frac{\text{SUM OF THE RAINFALL TOTALS FOR EACH SYNOPTIC FLOW PATTERN}}{\text{NUMBER OF RAINDAYS FOR EACH SYNOPTIC FLOW PATTERN}}$$

For example a station recorded 10 raindays under cyclonic easterly airflows. The total rainfall for the 10 days is 240mm. Using the above formula the average daily rainfall under cyclonic easterly is 240/10 = 24mm.

The above analysis can be used together. For axample Akaroa has a probablity of 0.40 chance of rainfall occurring on a anticyclonic southerly day. Its average daily rainfall total for that synoptic flow pattern is 15mm. So when it does rain under anticyclonic southerly conditions, its average daily rainfall pattern is likely to be 15mm.

Several extreme rainfall events occurred in the study area. Weather charts and maps were drawn up to assess the nature of these events.

7.4 SYNOPTIC CLIMATOLOGY OF RAINFALL PATTERNS

This section examines the daily rainfall climate of the study area using maps. The daily rainfall climate of the study area is discussed in three parts:

1) To determine the dominant rain-bearing wind direction in percentage terms. Nine representative stations were used in this analysis.

2) The probability of rainfall occurring under different synoptic flows.

3) Average daily rainfall totals under different atmospheric circulations. This subsection examined the following two factors:

a) The spatial variation of average daily rainfall totals for each of the 27 atmospheric circulations.

b) Which atmospheric circulation types produce significant rainfall totals.

The above analysis is based on approximately 35 stations over the study area using 1981 to 1985 daily rainfall (≥1mm) totals. The two main exceptions to this rule are Lyttelton (1978-1980 daily rainfalls) and M^{C} Queens Valley (1978 daily rainfalls). It must be remembered that this period was dominated by drought conditions and a strong negative phase of the Southern Oscillation during 1982-83 period.

7.4.1 DOMINANT RAIN- BEARING WINDS

The 27 synoptic circulations will be discussed in nine

The nine stations used in this analysis are Christchurch, Lincoln, Godley Head Lights, Living Springs, Magnet Bay, Akaroa, Okuti, Le Bons Valley, and Little Akaloa Bay. Living Springs substitutes for Allandale which closed down in 1974.

The eight main wind directions (S, SW, W, NW, N, NE, E, SE) plus a non directional category were used for determining the dominant rain bearing winds. Each rainday for the period 1981-85 was categorized into one of nine airflow types. The following formula was used to determine the % of raindays (1981-85) that came from each of the nine airflow types:

$$\frac{\text{SUM OF RAINDAYS FOR ONE OF THE NINE AIRFLOW TYPES}}{\text{SUM OF THE RAINDAYS (1981-85)}} * 100\%$$

Table 7.1 shows the % of the rain days from each category for the nine stations. Southweaterly flow shows up as being the dominant rain-bearing wind. The percentage figures are slightly higher over Banks Peninsula than the surrounding plains area. Southerly circulation is the next dominant flow direction, followed by northeasterly and non-directional circulations. Overall 50 to 60% of the rain-bearing winds come from the southerly (SE to SW circulations) quarter. Easterly, northerly, and westerly airflows are the least dominant rain-bearing direction.

7.4.2 PROBABILITY OF RAINFALL UNDER DIFFERENT SYNOPTIC FLOWS

This section examines the daily rainfall climate of the study

TABLE 7.1 PERCENTAGE FRQUENCY OF RAIN BEARING WINDS AT NINE STATIONS OVER THE STUDY AREA

STATIONS

	CH-CH*	LINCOLN	AKAROA	OKUTI	LIVING SPRINGS	MAGNET BAY	LITTLE AKALOA	LE BONS BAY	GODLEY HEADS
SE	9.1	9.7	7.8	10.1	11.2	9.3	8.6	7.9	8.4
SOUTH	15.4	15.7	14.1	16.1	14.5	15.1	13.9	14.6	14.9
SW	29.4	30.5	34.3	35.0	25.0	33.7	34.3	35.1	32.0
WEST	4.0	3.6	4.2	2.6	4.3	4.7	3.6	3.4	2.5
NW	8.1	9.9	7.2	7.0	13.0	9.8	7.3	7.9	8.7
NORTH	4.9	2.7	1.6	1.9	2.5	2.0	2.6	2.6	2.5
NE	12.6	12.1	10.8	10.8	11.2	9.3	11.6	11.3	12.4
EAST	3.5	3.4	7.0	3.1	2.2	2.7	3.9	3.9	4.0
ND[a]	12.9	12.3	13.1	13.4	15.9	13.5	14.2	13.3	14.6

* CHRISTCHURCH

a NON-DIRECTIONAL

categories using the eight major directions plus a non-directional category. Each category therefore has three synoptic circulation types such as anticyclonic southeasterly, cyclonic southeasterly, and unspecified southeasterly. Unspecified easterly is not examined due to insufficient days of this type. Maps are not presented for circulations that result in rainfall probability over study area being less than 0.10. Before the nine categories are discussed separtely, an overall summary will be given.

Cyclonic airflows have the highest probability of rainfall occurring while anticyclonic airflows has the lowest. Unspecified airflows are between the two extremes. Rainfall is least likely under anticyclonic and unspecified west to northerly circulations, and non-directional anticyclonic conditions. Areas exposed to the prevailing wind usually have higher rainfall probability.

<u>Southeasterly circulations</u>

All three maps show similar patterns (Figure 7.1a). Areas exposed to the southeast have the highest rainfall probability. This is particularly so for the higher altitude regions such as the hills surrounding Akaroa Harbour. The northern region of the study area, from Pigeon Bay to Lyttelton Harbour and eastern areas of Christchurch city, have the lowest probability of rainfall. this is due to sheltering effects of the hills to the south. Higher rainfall probability occurs under cyclonic southeasterly circulations.

Southerly circulations

Although the three maps show similar patterns (Figure 7.2a) the anticyclonic southerly map is the least complicated while the unspecified southerly map is quite complex. The three maps tend to show that areas exposed to the south have a higher probability of rainfall while areas sheltered from the southerly airflow have the lowest probability.

Under anticyclonic southerly circulations, the southeast to easterly regions of Banks Peninsula have higher rainfall probabilities while Lyttelton Harbour and eastern parts of Christchurch have the lowest probability. The pattern suggests that anticyclones move in from the west resulting in a eastward migration of showers over the study area. Cyclonic southerly also shows a similar pattern but with a larger area of south and eastern areas having higher rainfall probability. The unspecified southerly map is quite complex but two trends tend to show up:

1) SW - NE decrease in rainfall probability across the surrounding plains.

2) SE - NW decrease in rainfall probability from southeast part of Banks Peninsula to eastern areas of Lyttelton Harbour.

Both are related to exposure to these southerly winds.

SOUTHWESTERLY CIRCULATIONS

The trend shown by all three maps is a decrease in rainfall probability on a southeast to northwest gradient line from southeast bays to the northern region (Christchurch city and Lyttelton Harbour) (Figure 7.3a). This indicates that the eastern region of Banks Peninsula is more exposed to southwesterly circulations than the rest of the study area. However the difference in rainfall probability across the study area is least under anticyclonic conditions but greatest under cyclonic conditions. This suggests greater instability of the airmass under cyclonic conditions with the Banks Peninsula hills acting as a trigger mechanism for convective cloud development resulting in showers. However notice that the northern region of Akaroa Harbour is somewhat sheltered from southwesterly circulations.

Westerly circulations

While anticyclonic and unspecified westerly circulations show similar rainfall probability maps the reverse is true for cyclonic westerly (Figure 7.4a). Both anticyclonic and unspecified westerlies have low rainfall probability through out the study area due to the sheltering effects of the Southern Alps. However there is a slight tendency for increased rainfall probability over the eastern region of

Banks Peninsula. Under cyclonic westerly, the western and southern plains area have the highest rainfall probability while the northern and eastern bays have the lowest. This indicates that cyclonic westerly airflows are quite moist with a spill over of precipitation reaching the surrounding plains area but dying out before reaching the eastern parts of Banks Peninsula. This suggests the stability of airfloe associated with the descending of airmasses after crossing the Southern Alps.

Northwesterly circulations

Northwesterly airflows show similar patterns to those of the westerly circulation. Anticyclonic and unspecified conditions have a uniform low rainfall probability (less than 0.15) over the study area while higher rainfall probability occurs on the surrounding plains area (Figure 7.5a).

Northerly circulations

All three airflow types show different spatial distribution of rainfall probability (Figure 7.6a). Under anticyclonic northerly airflows the variation in rainfall probability is very similar ascross the study area and very low. Under unspecified northerly airflows, higher rainfall probability occurs on the surrounding plains area and the northern and eastern bays (exposed to the north). Cyclonic northerly airflows show quite a complex spatial pattern which does not seem to be related to esposure to the north. The higher rainfall probability occurs on the western and southern surrounding plains area while unexpectedly the lowest rainfall probability occurs on the Port Hills. The reason for this pattern is unknown to the author but may be related to insufficient rainfall stations covering the study area for this analysis.

Northeasterly circulations

The three maps tend to indicate the following points:

1) The northern and eastern bays area have higher rainfall probabilities while the southwest region of the study area has the lowest.

2) Lyttelton Harbour and the surrounding hills have higher rainfall probabilities due to exposure to the northeasterly airflows. Figure 7.7a shows the spatial distribution of rainfall probabilities under these circulation flows.

Easterly circulations

Anticyclonic easterly airflows show an east-west decrease in rainfall probability from the eastern bays to the southwest region of Banks Peninsula, an area sheltered from easterly flows (Figure 7.8a). An increase in rainfall probability occurs on the plains once the sheltering effects of Banks Peninsula becomes less important. The slightly higher rainfall probability around the western end of

Lyttelton Harbour relates to forced ascent of the easterly airflow. Under cyclonic conditions very similar high rainfall probabilities occur over the study area.

Non-directional circulations

Figure 7.9a shows the rainfall probability of these three airflow types. Under anticyclonic conditions rainfall probability is very low showing a slightly higher probability in the eastern region of Banks Peninsula. This suggests that this is the last area to lose the remaining showers from the rain-bearing winds. Under cyclonic conditions the southeast region of Banks Peninsula has the higher rainfall probability while the northern region has the lower rainfall probability. This suggests that many of the depressions situated over the study area have a southeasterly to southerly wind component in them. Unspecified conditions have a fairly uniform pattern with a slight maximum over the southeast region of Banks Peninsula.

The following nine pages are the maps of rainfall probabilities and below them, the average daily rainfall totals over the study area.

FIGURE 7.1 RAINFALL PROBABILITY AND AVERAGE DAILY RAINFALL TOTALS UNDER SOUTHEASTERLY CIRCULATIONS OVER THE STUDY AREA

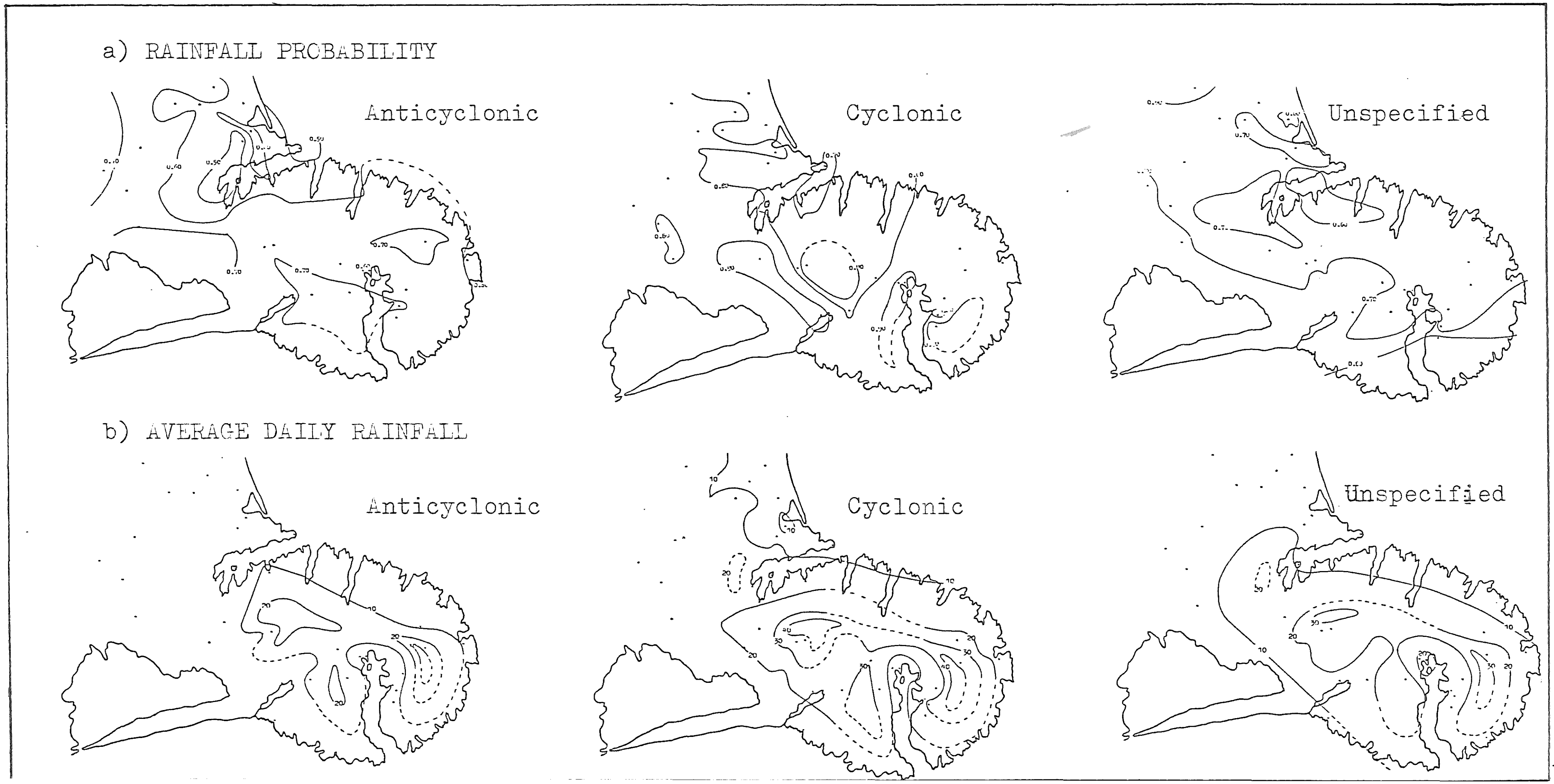


FIGURE 7.2 RAINFALL PROBABILITY AND AVERAGE DAILY RAINFALL TOTALS UNDER SOUTHERLY CIRCULATIONS OVER THE STUDY AREA

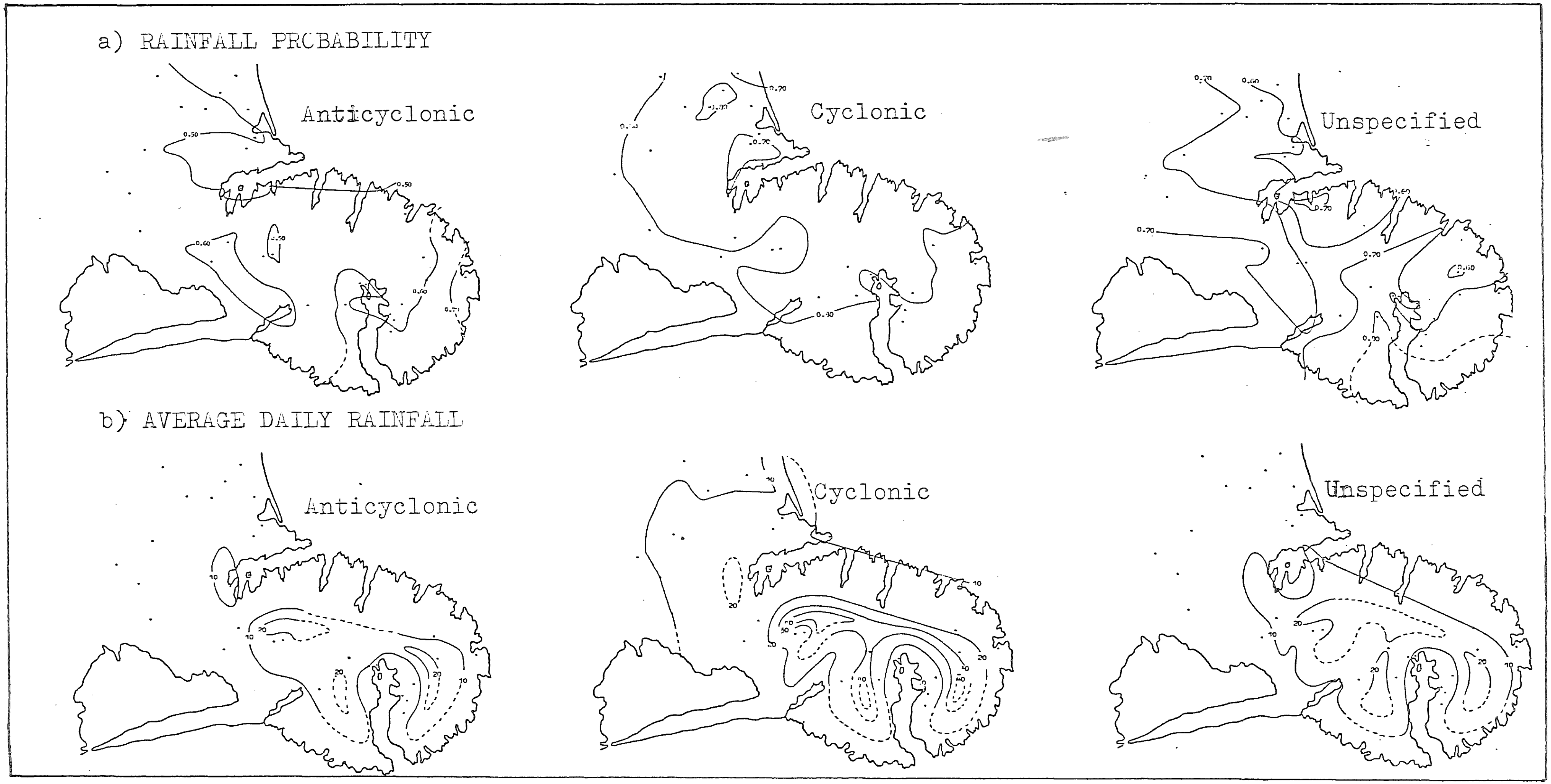


FIGURE 7.3 RAINFALL PROBABILITY AND AVERAGE DAILY RAINFALL TOTALS UNDER SOUTHWESTERLY CIRCULATIONS OVER THE STUDY AREA

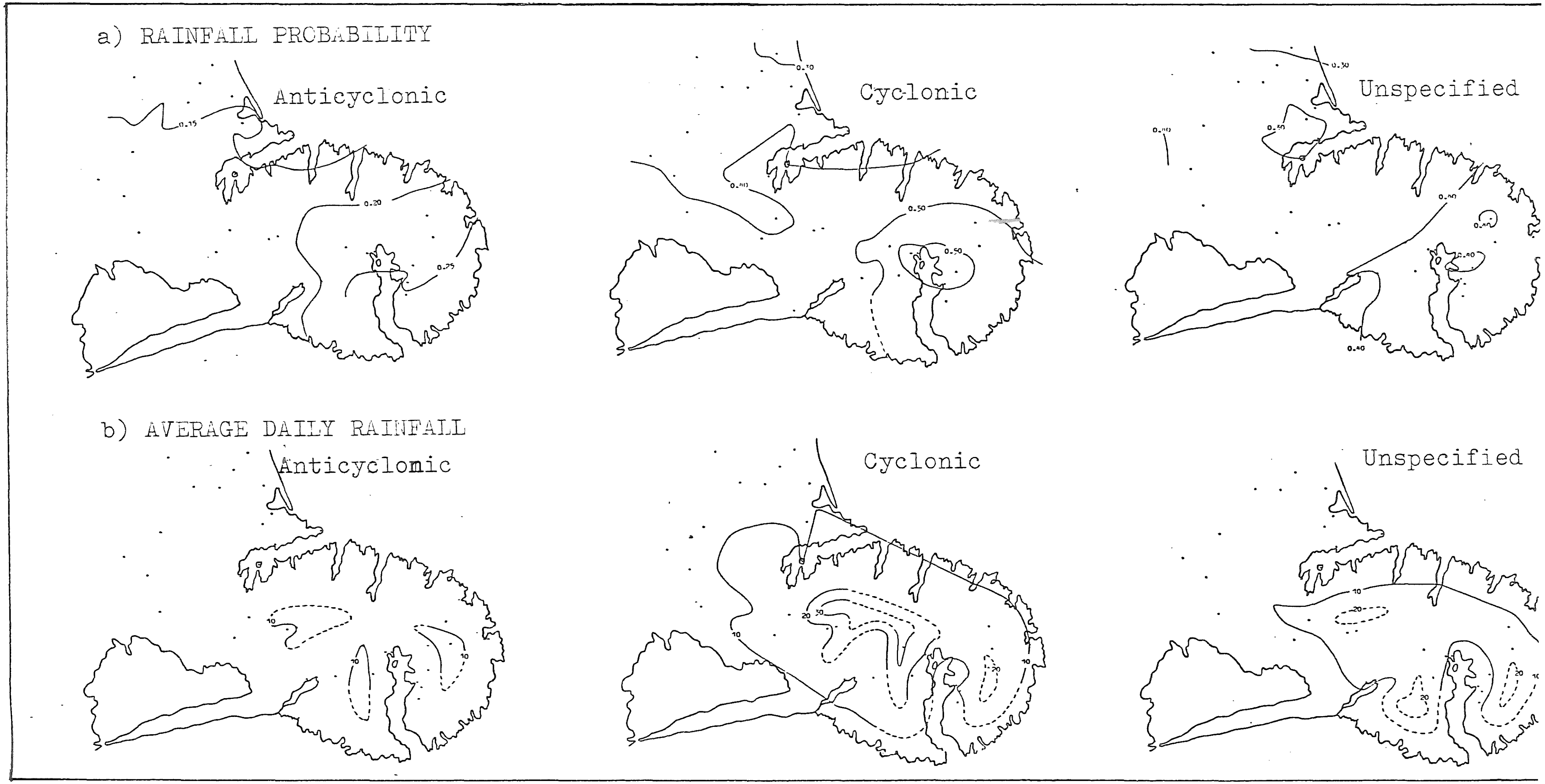


FIGURE 7.4 RAINFALL PROBABILITY AND AVERAGE DAILY RAINFALL TOTALS UNDER WESTERLY CIRCULATIONS OVER THE STUDY AREA

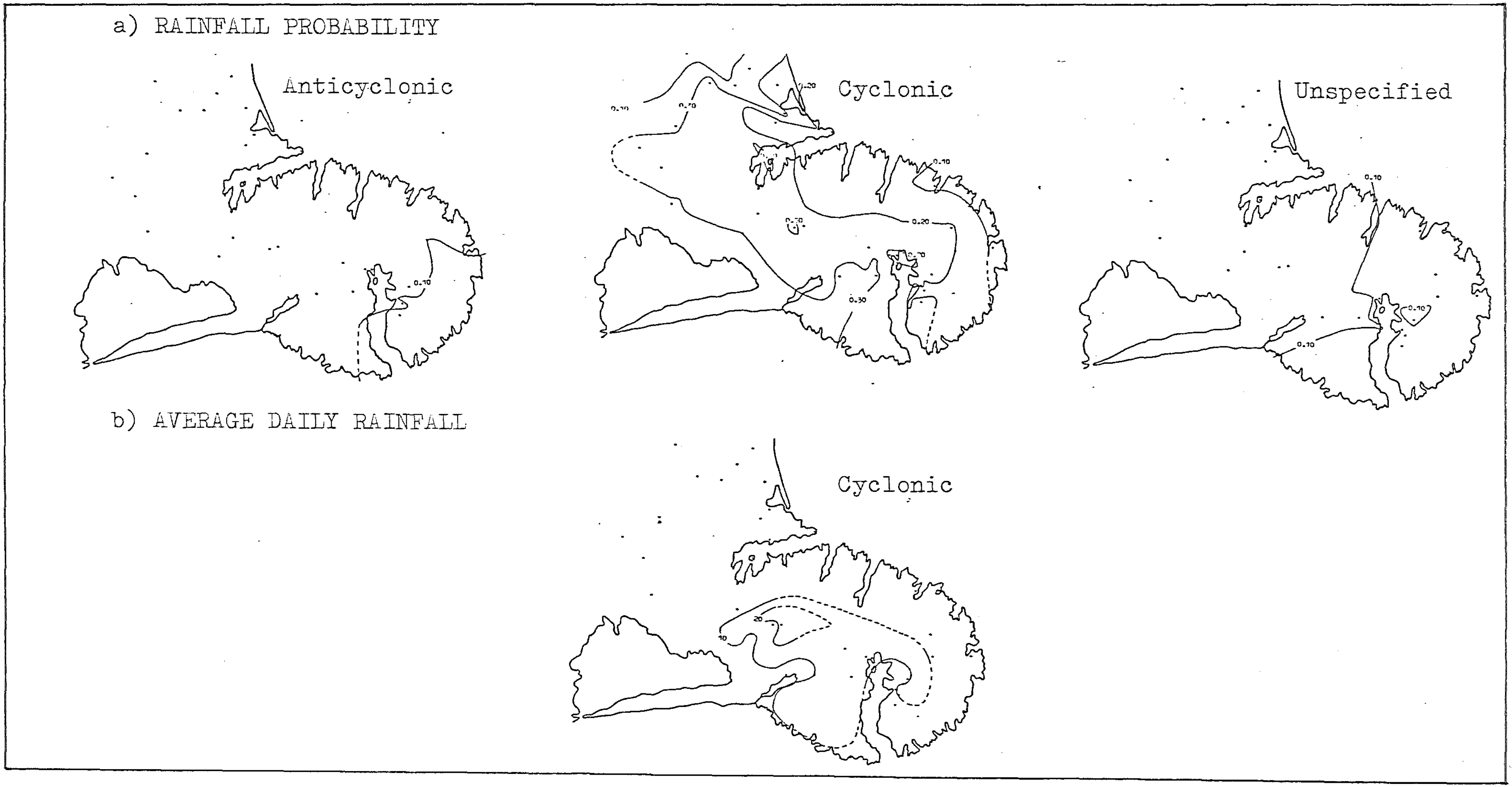


FIGURE 7.5 RAINFALL PROBABILITY AND AVERAGE DAILY RAINFALL TOTALS UNDER NORTHWESTERLY CIRCULATIONS OVER THE STUDY AREA

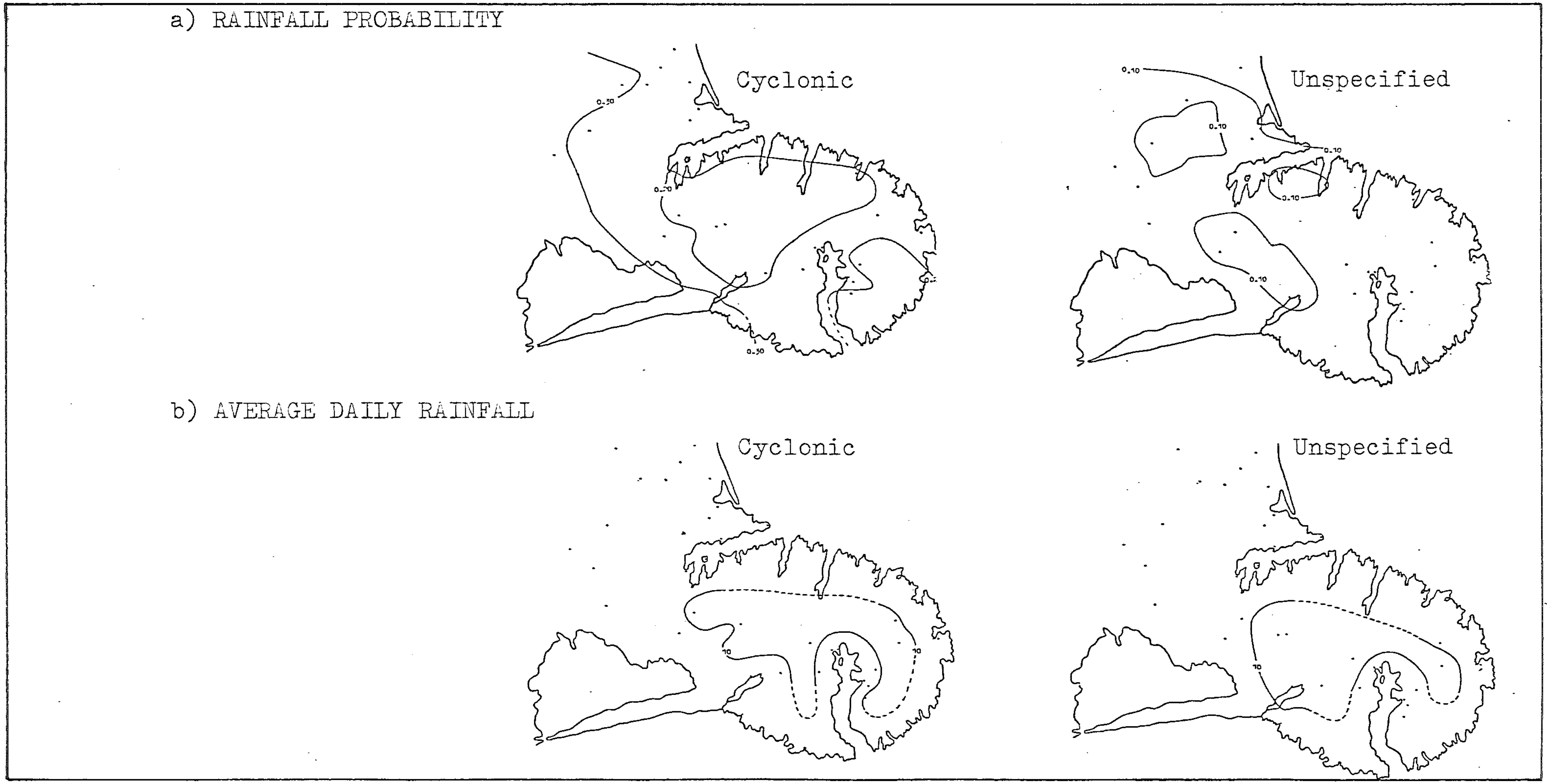


FIGURE 7.6 RAINFALL PROBABILLITY AND AVERAGE DAILY RAINFALL TOTALS UNDER NORTHERLY CIRCULATIONS OVER THE STUDY AREA

a) RAINFALL PROBABILITY

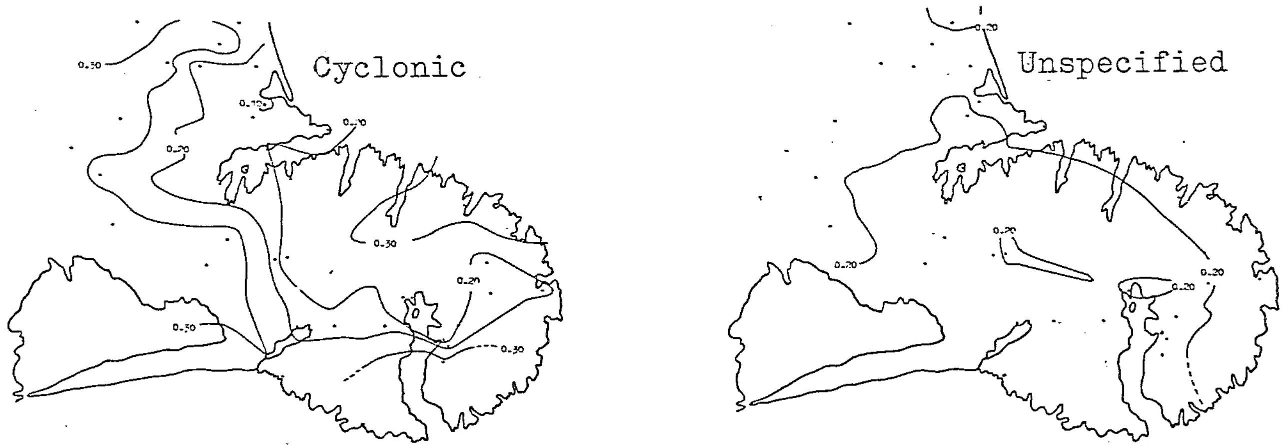


FIGURE 7.7 RAINFALL PROBABILITY AND AVERAGE DAILY RAINFALL TOTALS UNDER NORTHEASTERLY CIRCULATIONS OVER THE STUDY AREA

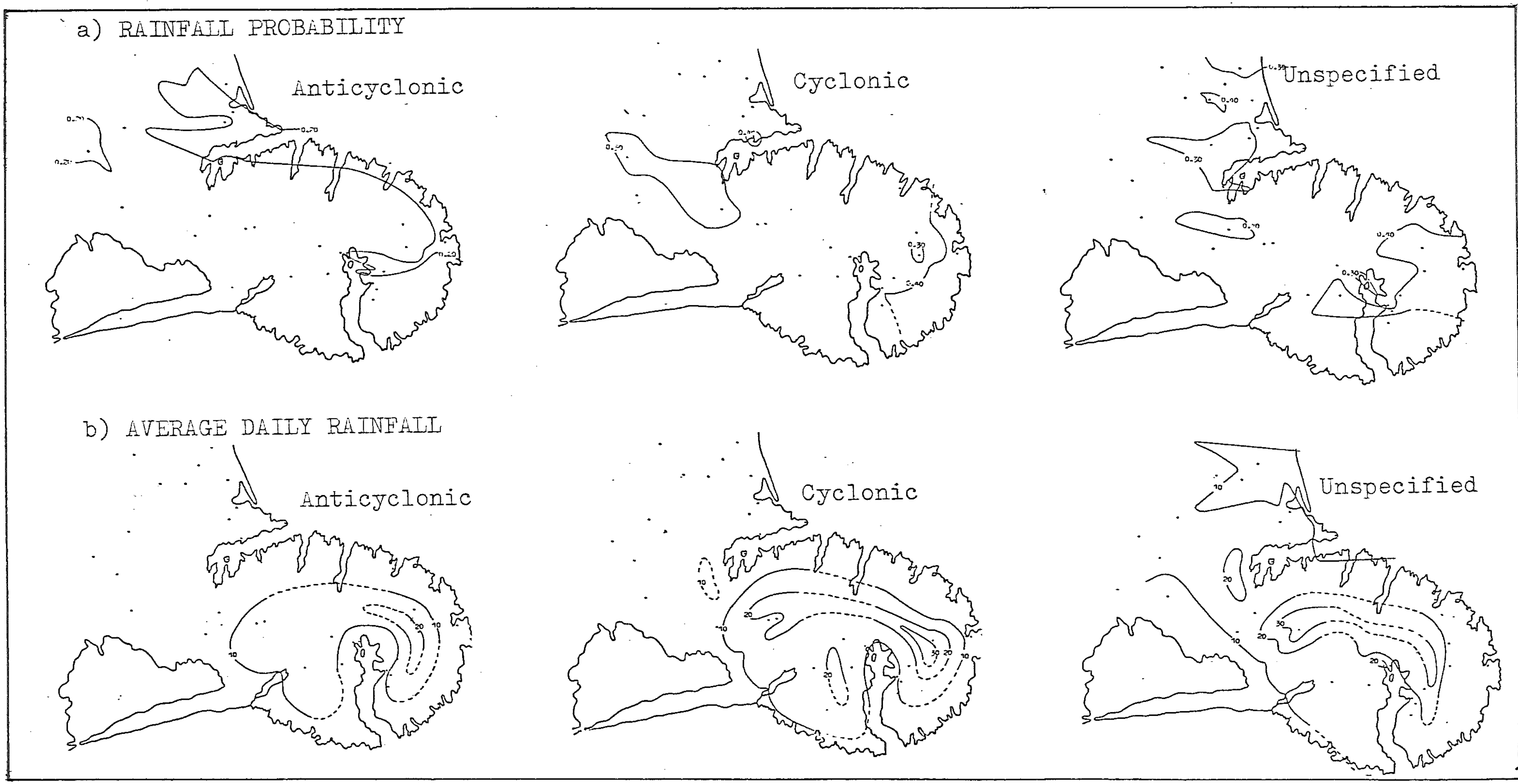


FIGURE 7.8 RAINFALL PROBABILITY AND AVERAGE DAILY RAINFALL TOTALS UNDER EASTERLY CIRCULATIONS OVER THE STUDY AREA

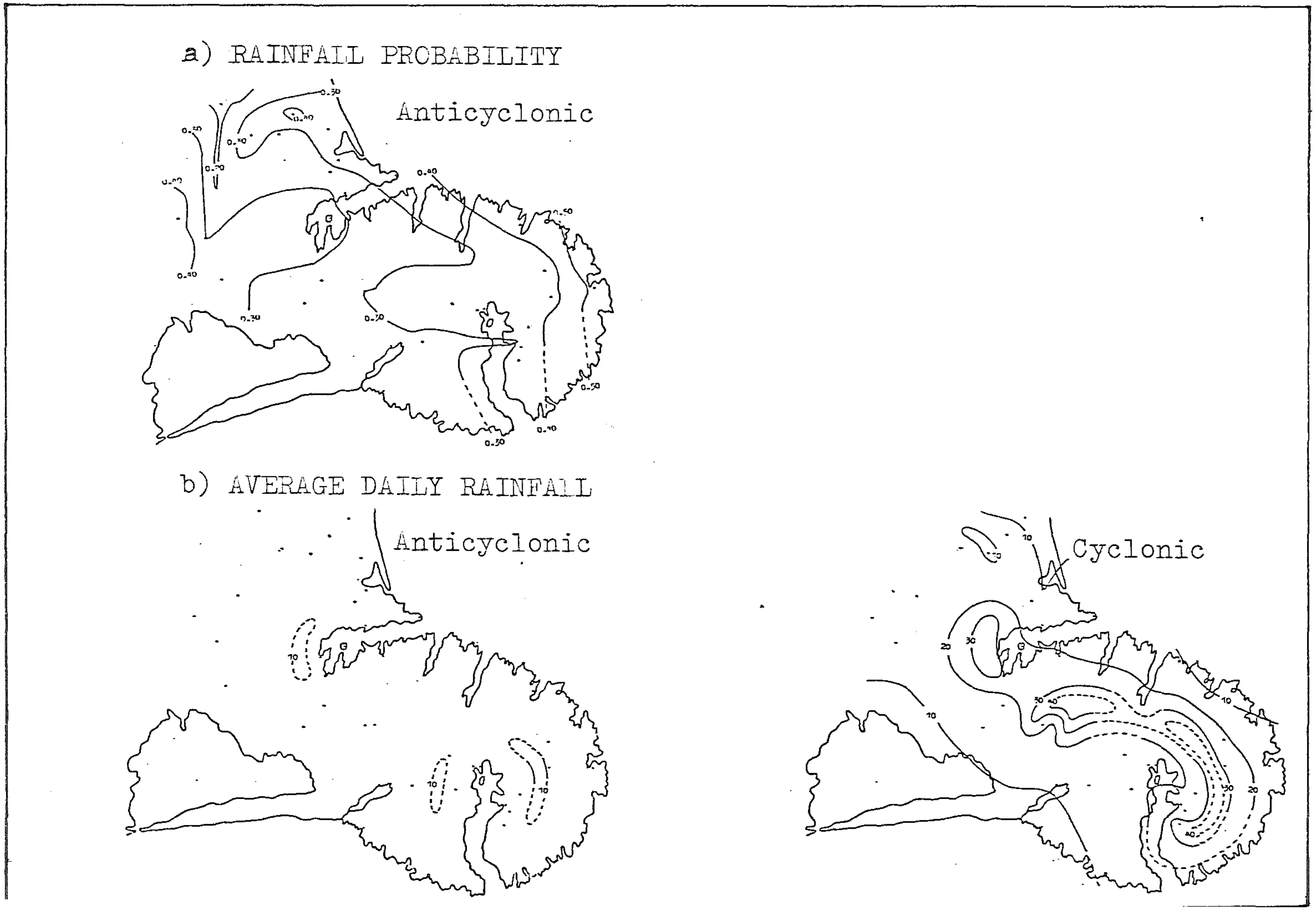
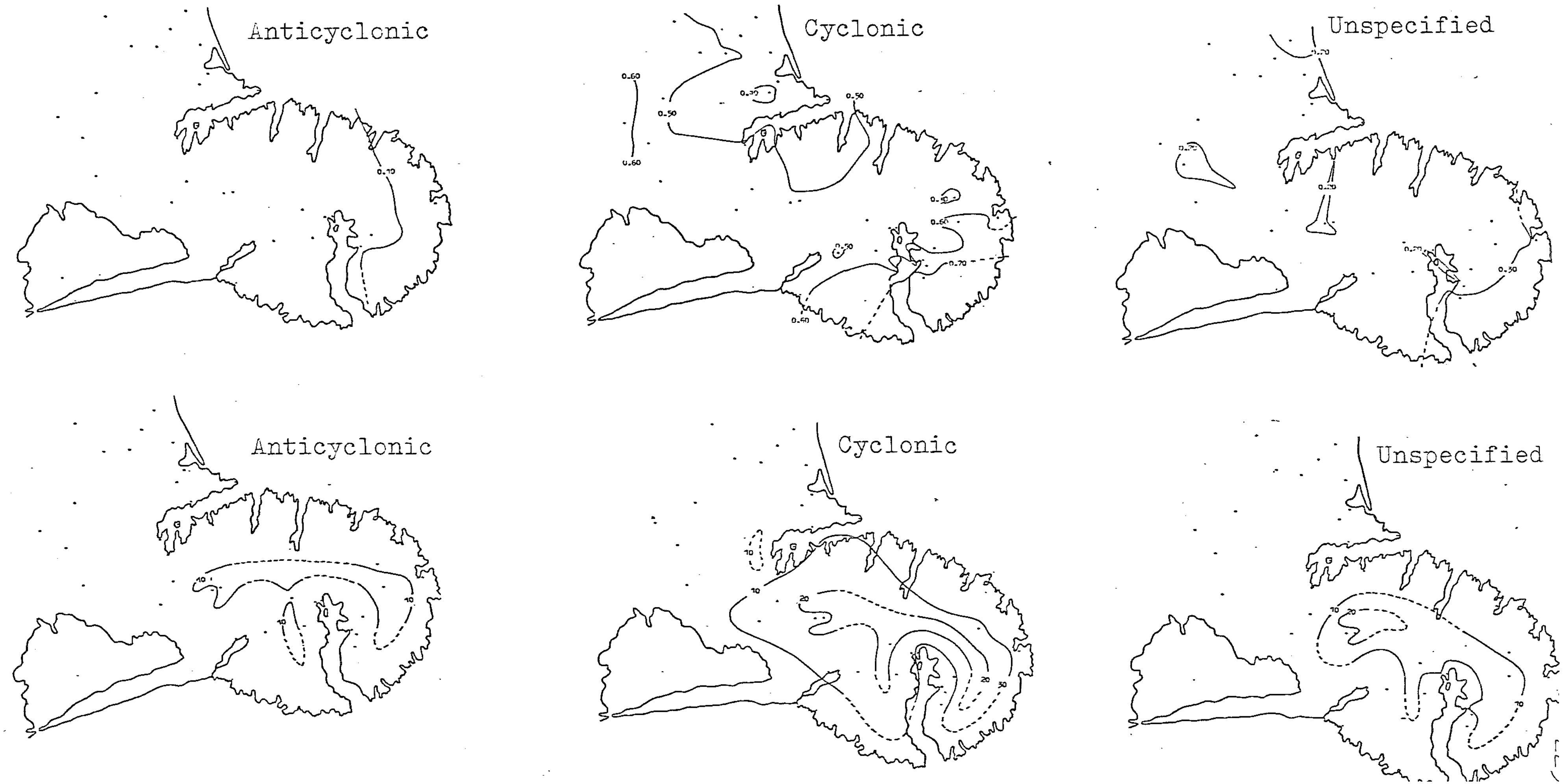


FIGURE 7.9 RAINFALL PROBABILITY AND AVERAGE DAILY RAINFALL TOTALS UNDER NON-DIRECTIONAL CIRCULATIONS OVER THE STUDY AREA

a) RAINFALL PROBABILITY



7.4.3 AVERAGE RAINFALL TOTALS UNDER DIFFERENT SYNOPTIC AIRFLOWS

This section examines the distribution of average daily rainfa totals over the study area under 27 synoptic flow patterns (Sturmaı et al 1984). As discussed in the previous section, the 27 synopti(flow patterns were categorized into nine sections using the eigh major wind directions plus a non-directional flow. An overview wil be given before each of the nine categories are discussed.

Cyclonic airflows produce the heaviest daily rainfall totals over the study area while anticyclonic airflows produce the lightest Unspecified airflows are between these two extremes. In terms of wind direction southeasterly to southwesterly airflows produce the heaviest daily rainfall totals, especially under cyclonic influence. Northeasterly and cyclonic easterly airflows can also produce quite heavy rainfall totals. The lowest rainfall totals occur under northwesterly and northerly airflows. The hilltops and summits of Banks Peninsula receive the heaviest rainfall totals while the coastal areas of Banks Peninsula and the surrounding plains area tend to receive the lowest totals. This indicates that forced ascent of air plays an important part in increased precipitation over Banks Peninsula.

Southeasterly circulations

All three maps (anticyclonic southeasterly, cyclonic southeasterly, unspecified southeasterly) show similar rainfall distribution over the study area (Figure 7.1b). The highest daily rainfall totals occur on the hilltops exposed to the southeast while the surrounding plains area dominantly receives the lowest rainfall totals. Under cyclonic southeasterly the lowest rainfall totals occur around eastern parts of Christchurch city and around Lyttelton Harbour area. This indicates that this area is sheltered by the hills to the southeast.

Southerly circulations

The three rainfall maps show similar variation to the rainfall distributoin shown in southeasterly airflows (Figure 7.2b). The main differences are:

1) The sheltering effect of Banks Peninsula is less effective around Christchurch area.

2) Higher daily rainfall totals occur arround the western end of Lyttelton Harbour.

3) The northern bays are somewhat sheltered from southerly airflows.

4) Daily rainfall is not as heavy as under southeasterly airflows.

Southwesterly circulations

Only areas around the three main hilltop areas receive significant daily rainfall totals under southwesterly airflows (Figure 7.2b). Heavier rainfall totals occur over a wider area of Banks Peninsula under cyclonic airflows. Most of the surrounding plains area dominantly receive less than 10mm of daily average rainfall under all three airflow types. The heaviest rainfall totals occur in the central hill areas of Banks Peninsula.

Westerly circulations

Under anticyclonic and unspecified westerly airflows the daily rainfall totals over the study area are generally below 10mm. Therefore no maps were presented. Only under cyclonic westerly flows does significant rainfall totals occur over the Banks Peninsula with the significant rainfall totals occurring over Mt Herbert area (Figure 7.3b).

Northwesterly circulations

All of the significant daily rainfall totals (above 10mm) occur over Banks Peninsula in areas of high altitude. Most of the surrounding plains area receives less than 6mm of rainfall under all three airflows types. Figure 7.4b shows the distributionof daily rainfall under unspecified and cyclonic conditions.

Northerly circulations

No maps are provided for these airflows as no large areas receive more than 10mm of daily average ranfall totals. Northerly airflows are the driest the study area experiences.

Northeasterly circulations

All three maps show a fairly similar rainfall pattern (Figure 7.7b). The hills surrounding the eastern and northern bays, and Mt Herbert area under unspecified conditions. Higher rainfall totals also occur around the Port Hills. The Christchurch region and Lyttelton Harbour entrance receive less than 10mm of daily rainfall under all three airflow types. Notice also the low rainfall totals in the southwest region of Banks Peninsula under these airflow types.

Easterly circulations

Cyclonic easterly flows produce the heaviest daily rainfall totals. The hilltop areas exposed to the east receive the heaviest daily rainfall totals, particularly the hills surrounding eastern and northern bays (Figure 7.8b). Notice the high rainfall totals over the Port Hills around the western end of Lyttelton Harbour. Lowest rainfall totals occurs around Christchurch city, surrounding plains southwest of Banks Peninsula and the southern bays area.

Non-directional circulations

Similar rainfall distributions occur over the study area under all three airflows (Figure 7.9b). The lowest daily rainfall totals occur on the surrounding plains and coastal regions of Banks Peninsula. The highest totals occur in the high altitude regions of Banks Peninsula. More significant rainfall occurs under cyclonic conditions over the study area than under anticyclonic conditions.

7.5 EXTREME HEAVY RAINFALL EVENTS

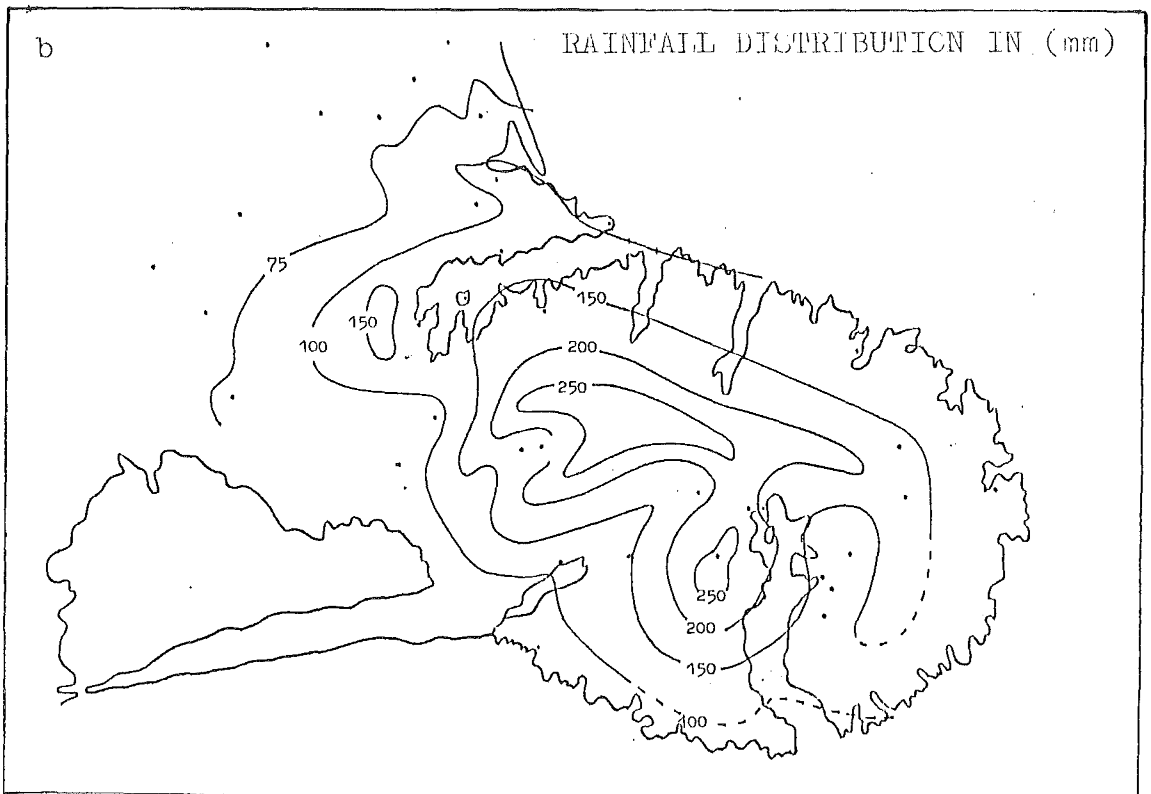
Three extreme rainfall events will be discussed briefly, looking at the rainfall distribution over the study area and the synoptic conditions. Surface weather charts will be provided for each of the three events. It should be noted that these heavy rainfall events have occurred in a dry spell period.

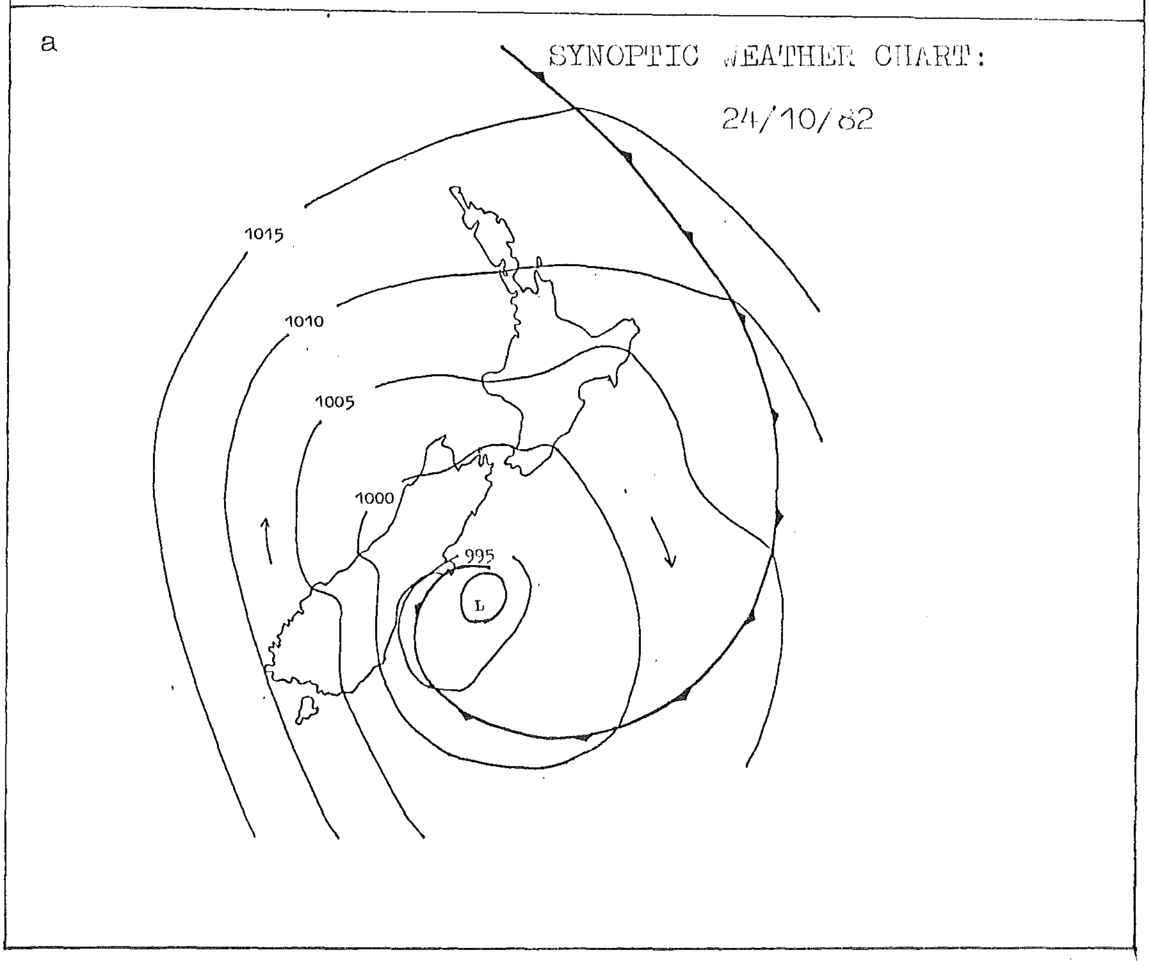
7.5.1 23rd - 26th OCTOBER, 1982

A low pressure system began to develop over Canterbury as a cold front moved over the Canterbury region. This low pressure system rapidly developed into a depression and deepened to the east of Canterbury resulting in a strong cyclonic southwesterly airflow over the study area. The depression then split up into two systems on the 25th with the main cantre moving slowly away from the South Island in a southwesterly direction on the 26th. An anticyclone was approaching from the west (Figure 7.10a).

The heaviest rainfall occurred on the 23rd and 24th when the low pressure was situated over or east of the Canterbury region.

FIGURE 7.10 RAINFALL DISTRIBUTION OVER THE STUDY AREA DURING 23th-26th OCTOBER, 1982, AND ACCOMPANYING WEATHER CHART





Various stations (Onawe, Okuti, Purau) received over 120mm of rainfall on these two days. Over this period the highest rainfall totals occurred on the hilltops exposed to the southwest and southeast (Figure 7.10b). This is the result of the forced ascent of moisture bearing winds in conditions already very favourable for convective cloud development.

7.5.2 17th - 22nd MAY, 1983

A low pressure centre developed on a cold front over the South Island with the main depression well south of New Zealand. This low pressure system developed into a depression and moved slowly southeast then northeast. As the depression moved northeast over the North Island, a ridge of high pressure developed over southern New Zealand resulting in a southeasterly airflow. The dominant airflow during this period was southeasterly but most of the rainfall fell on the 18th May when cyclonic southwesterly conditions prevailed (Figure 7.11a).

The higher rainfall totals occurred on the hills surrounding Akaroa Harbour and Mt Herbert region where the heaviest rainfall totals would have occurred. The forced uplift of an unstable airmass over Banks Peninsula resulted in incresed precipitation. Over the surrounding plains area away from the hills, the lightest rainfall totals occurred (Figure 7.11b).

FIGURE 7.11 RAINFALL DISTRIBUTION OVER THE STUDY AREA DURING17th-22nd MAY, 1983, AND ACCOMPANYING WEATHER CHART

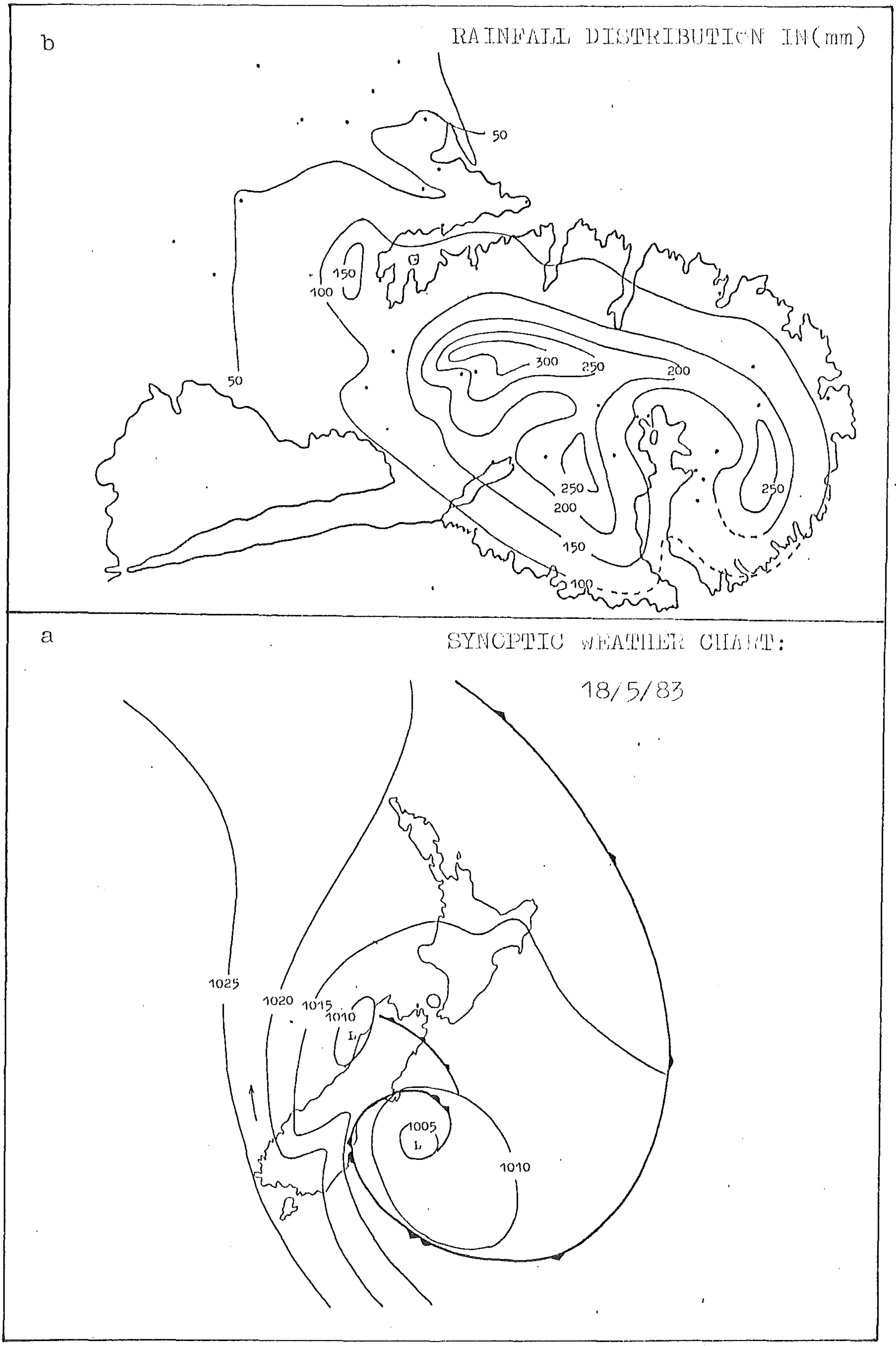
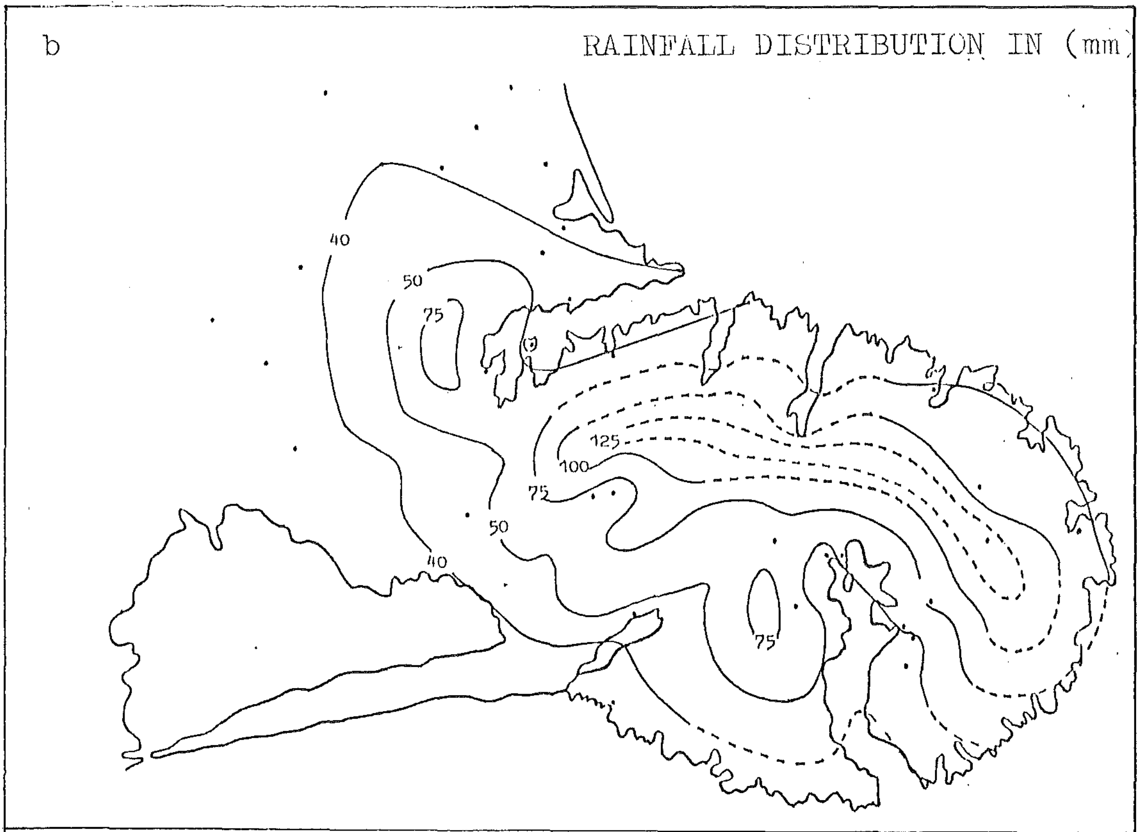
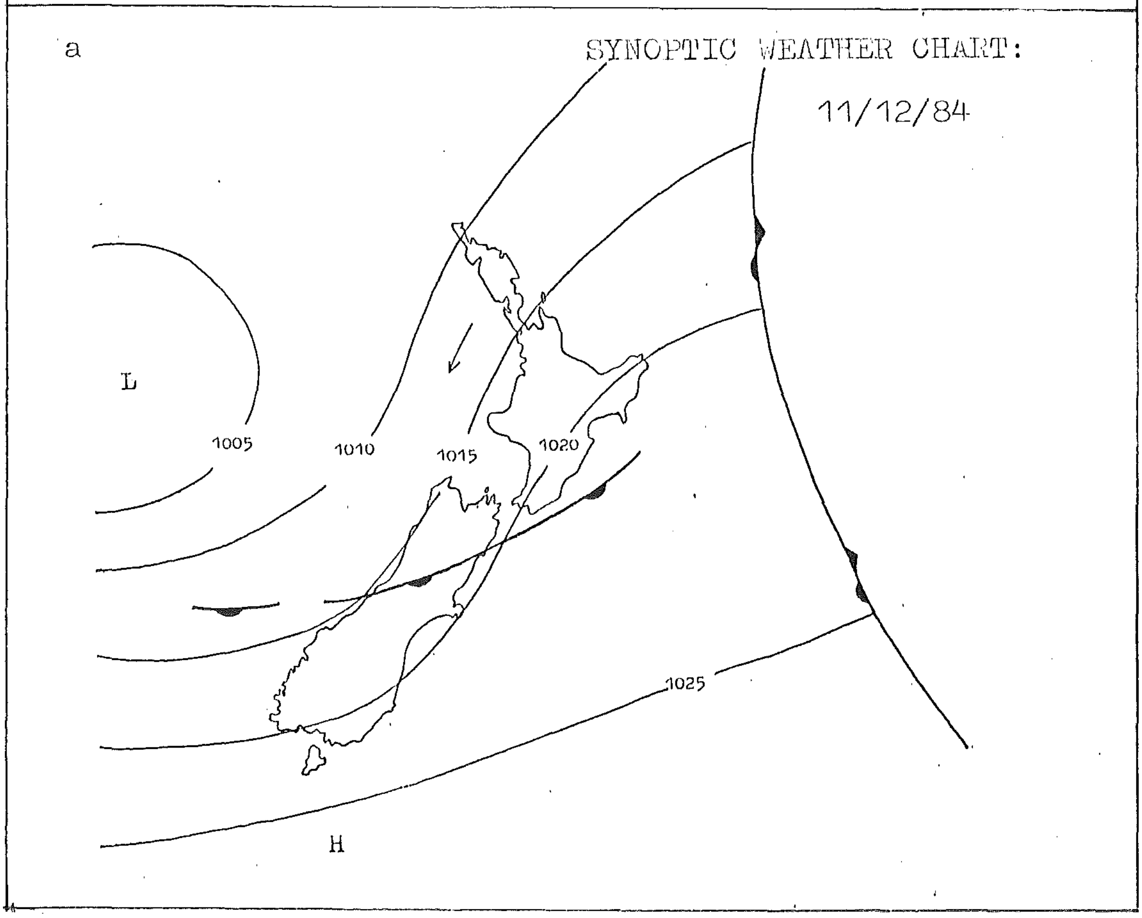


FIGURE 7.12 RAINFALL DISTRIBUTION OVER THE STUDY AREA DURING 10th-12th DECEMBER, 1984, AND ACCOMPANYING WEATHER CHART





7.5.3 10th - 12th DECEMBER, 1984

Over these three days an east to northeast airstream flowed over the Canterbury region as an anticyclone moved east-southeast to the south of New Zealand. A trough of low pressure containing several fronts moved southeast from the Tasman Sea and over the South Island. The heaviest rainfall occurred as the trough passed over the South Island (Figure 7.12a).

The heaviest rainfall occurred on the hills exposed to the northeast (hills surrounding northern abd eastern bays). High rainfall totals are also seen over the Port Hills. Lighter rainfall occurred on the plains southwest of Banks Peninsula and coastal regions of the southern bays area (Figure 7.12b). This area is sheltered under northeasterly airflow due to the hills to the north.

7.6 CONCLUSION

This chapter examined the daily rainfall patterns over the study area and its relationship to daily synoptic flow patterns. Approximately 30 to 35 % of rain days come from southwesterly airflows. However they usually do not bring a large quantity of rainfall whereas cyclonic southerly to easterly are associated with significant rainfall totals. 50 to 60% of the raindays came from southerly quarter winds (southeast to southwest). Northeasterly winds were also important rain-bearing winds.

The highest rainfall probability occurs under cyclonic airflows. This is particularly so when associated with east ot southerly airflows. Lowest rainfall probability occurred under anticyclonic conditions, particularly associated with westerly to northerly airflows. It was found that areas exposed to certain airflows had higher rainfall probability while areas that were sheltered had lower probabilities.

The highest daily rainfall totals occurred over the study area when cyclonic conditions, associated with northeasterly to southwesterly airflows, prevailed. Hill areas exposed to these rain-bearing winds had the highest average daily rainfall totals, while areas that were sheltered had lowest daily rainfall figures. The surrounding plains area tended to consistently record the lowest daily rainfall figures in all synoptic conditions. This indicates the importance Banks Peninsula has on rain-bearing airflows by forcing them to rise over the hills resulting in increased precipitation. However in rainfall probabilities such as cyclonic westerly and northwesterly conditions, the higher rainfall probability can occur on the surrounding plains area.

The extreme rainfall events indicated that depressions situated over or east of Canterbury results in the heaviest rainfall totals over the study area. It is also apparent that heavy rainfalls can occur at any time of the year, and in the middle dry spells.

It must be remembered that these results are based on approximately 35 stations over the study area which are dominantly grouped over the surrounding plains area and the two harbours. Therefore many of the local variations that occur in the bays are likely to be missed. Also the 1981 - 1985 period was quite a dry period for the study area.

CHAPTER EIGHT

CONCLUSION

8.1 SUMMARY

Previous researchers of Canterbury's climate have included Banks Peninsula in their studies, but have not specifically looked at Banks Peninsula in great detail. This investigation has attempted to provide a better understanding of the climatology of Banks Peninsula and the surrounding plains area. It is hoped that this investigation will provide the necessary incentive for further research into this area, particularly as increased tourism and diverification of agriculture is likely. The study took into the main controlling factors that influence Canterbury's climate such as the Southern Alps and proximity to sea.

The main research objectives of this study were:

1) Providing a detailed background climatology of Banks

Peninsula.

2) Examination of observed climatic trends over the study area and their relationship with flow trends.

3) Synoptic climatology of rainfall over the study area.

8.1.1 HOMOGENEITY OF CLIMATIC RECORDS

One of the most important components involved in climatic studies is assessment of the reliability of climatic records. This is particularly so when conducting research into climatic trends/ changes as unreliable data will result in an incorrect picture .

Before homogeneity analysis was conducted, following the lines proposed by Jones et al (1985) and Conrad and Pollard (1950), the stations were subjectively grouped together on the basis of topographic features. Rainfall and temperature data used slightly different homogeneity analysis techniques as discussed in Chapter 3. A BMDP package called "*Missing Value* " was used to estimate suspected data shown up in the homogeneity analysis, and for missing values. These values were checked before the improved climatic records were used.

8.1.2 BACKGROUND CLIMATOLOGY

Previous research has used rainfall stations on Banks Peninsula for broader scale climatic studies over the Canterbury region. Most studies have not specifically examined Banks Peninsula's climate. It was therefore necessary to present a comprehensive background of Banks Peninsula before analysis of climatic trends could be conducted.

The analysis indicated that despite the many similarities to the surrounding plains climate, Banks Peninsula showed significant differences due to two main factors:

1) The peninsula projects out from the Canterbury Plains making it more exposed to rain bearing winds.

2) Altitudinal effects on rainfall distribution.

This has resulted in a great variation of average annual rainfall totals (from 565mm to approximately 2000mm) over the peninsula because of its complex topography. Banks Peninsula generally has a wetter climate in comparison to the surrounding plains area at similar altitudes.

The warmer temperatures experienced over Banks Peninsula in comparison to the surrounding plains area are related to two main factors:

1) Being less prone to katabatic drainage of cold air from the plains.

2) Closer proximity to the sea.

This was particularly so for minimum temperatures in the colder months of the year.

8.1.3 OBSERVED CLIMATIC TRENDS AND THEIR RELATIONSHIP TO SYNOPTIC FLOW TRENDS

Ten and thirty year moving trends were used to determine observed climatic trends over the study area. Ten year trends examined the shorter term climatic fluctuations while thirty year trends examined the longer term climatic trends. As expected the thirty year trend responded slower than the ten year trend and was less extreme in terms of fluctuations in the climatic trends. In terms of cross-relating the two scales, only prolonged wet, normal, and dry periods of the ten year moving trend scale were detected in the thirty year moving trend scale as short term fluctuations were smoothed over.

The study area's climate has observed many fluctuations and trends since records began. The wetter regions of Banks Peninsula fluctuated much more widely than the drier regions. Extensive normal to dry conditions were found to occur over the study area, as in the 1960's to early 1970's. This was particularly so for spring rainfall. However extensive wet periods have also occurred. The most prolonged wet period occurred in the 1940's and 50's with historical writing commenting on the numerous floods that occurred in the Canterbury region at that time. This wet spell lasted the longest in the autumn season. An extensive cool period occurred in the study area during the late 1920's to early 1950's which was detected on both time scales. Historical writings commented quite extensively on the severe winters with heavy frosts and frequent snowfalls during this period. The climatic warming that has occurred since 1950, observed by other writers (Salinger 1979,1980, Trenberth 1977), has been related to two factors:

1) A change in broad climatic elements resulting in warmer temperatures over New Zealand.

2) A change in the microclimate surrounding the station resulting in warmer temperatures.

It was considered by the author that changes in synoptic flow patterns would be an important influencing factor on observed climatic trends. Multiple regression analysis, using Sturman's circulation indices, was used to determine the significance of synoptic flow trends on observed rainfall and temperature trends. On the 10 and 30 year moving trend scale, synoptic flow trends were the most dominant factor accounting for observed changes in rainfall and temperature trends. On a monthly to annual scale synoptic flow patterns were not as significant. Other factors were important as well.

Rainfall trends had a positive relationship with cyclonicity, southerly, and easterly circulations, and a negative relationship with westerly and northerly circulations. This analysis sugessted that an increase in meridional flows tends to lead to wet periods while increased zonal flows tends to lead to drier conditions.

In terms of temperature trends, their relationship with synoptic circulation was more significant than rainfall, especially maximum temperature trends. Southerlies were shown to have the most significant negative impact on temperature while increased cyclonic activity tended to increase temperature in the colder part of the year. The results indicated that maximum temperatures are more sensitive to changes in synoptic flow trends than minimum temperatures.

8.1.4 SYNOPTIC CLIMATOLOGY OF DAILY RAINFALL VARIATIONS

An analysis was conducted on the relationship of daily rainfall patterns and distribution over the study area to daily synoptic flows using Sturman's classification scheme. This analysis was based on the 1981 to 1985 period. Southwesterly airflows were found to be the dominant rainbearing winds accounting for 30 to 35 % of the raindays over the study area while southerly quarter winds accounted for 50 to 60 %. The highest rainfall probabilities occurred under cyclonic airflows, particularly when associated with easterly to southerly airflows. It was under these conditions that significant average daily rainfall totals occurred over the study area, especially over the Banks

Peninsula hills. Anticyclonic conditions in association with westerly to northerly airflows were least likely to have rainfall and recorded the lowest daily rainfall values.

The study of extreme rainfall events suggested that heavy rainfall occurs when depressions are situated in two positions:

1) Over or east of Canterbury.

2) over the North Island.

These situations result in moisture bearing winds flowing over the study area leading to heavy rainfall.

8.2 SUGGESTIONS FOR FURTHER RESEARCH

The thesis presented here is the first major climatic research, to the authors knowledge, to be concerned with the Banks Peninsula. Consequently a number of questions and areas for further research has arisen.

Although a detailed background climatology of Banks Peninsula was presented, there were large areas where rainfall contour lines had to be generalised or estimated, particularly high altitude areas. Investigations could be conducted in some of the accessible bays to determine local variations of rainfall patterns in this complex topographic region. The relationship of rainfall with altitude could also be examined. A series of rain gauges from one of the major ridges to the other would enable us to determine the variation in rainfall patterns on different slope aspects under varying synoptic flow conditions. A series of rain gauges over high altitude areas would help to improve our estimation of rainfall totals in these area and would be useful in understanding the effects of topography on rainfall distribution.

An examination could be conducted of the realationhip between forced ascent of airflows over Banks Peninsula and its contribution to increased rainfall with height. A studying examining the mechanics of this process would be useful, as it could be applied in other hill country areas.

Many of the observed climatic trends showed cyclic fluctuations which were not fully explained. Research into these cyclic variatons could be conducted to determine the causal factors. The thesis indicated that trends in synoptic flow were the most important factor in determining rainfall and temperature trends. This analysis could be conducted in other regions of the South Island. This would be particularly useful for determining how changes in synoptic flow affects rainfall and temperature trends over the South Island. Other climatic elements such as sunshine, wind speed and direction, and raindays could be related to synoptic flow.

A break down of the five circulation circulation indices into the eight major wind directions plus a non-directional category could be useful to determine more specifically the influence of airflow direction on rainfall and temperature trends.

In terms of synoptic climatology daily rainfall patterns over the study area, installation of rain ga~~s~~uges over the bays and hilltops of Banks Peninsula would help to improve rainfall probability and daily rainfall maps provided in this thesis. These maps could be used in association with civil defense and local meteorological to help predict likely rainfall totals under different synoptic flows and issue possible flood warnings to local farmers over Banks Peninsula.

This thesis could not analyses temperature patterns and variations over Banks Peninsula to any large extent due to the sparseness of temperature stations. Further research could examine the temperature variation over Banks Peninsula and the influence of synoptic flow patterns on temperature but tjis would require a more comprehensive set of temperature stations. Also a series of temperature stations could be established across major ridges to determine the variation in temperature with altitudes.

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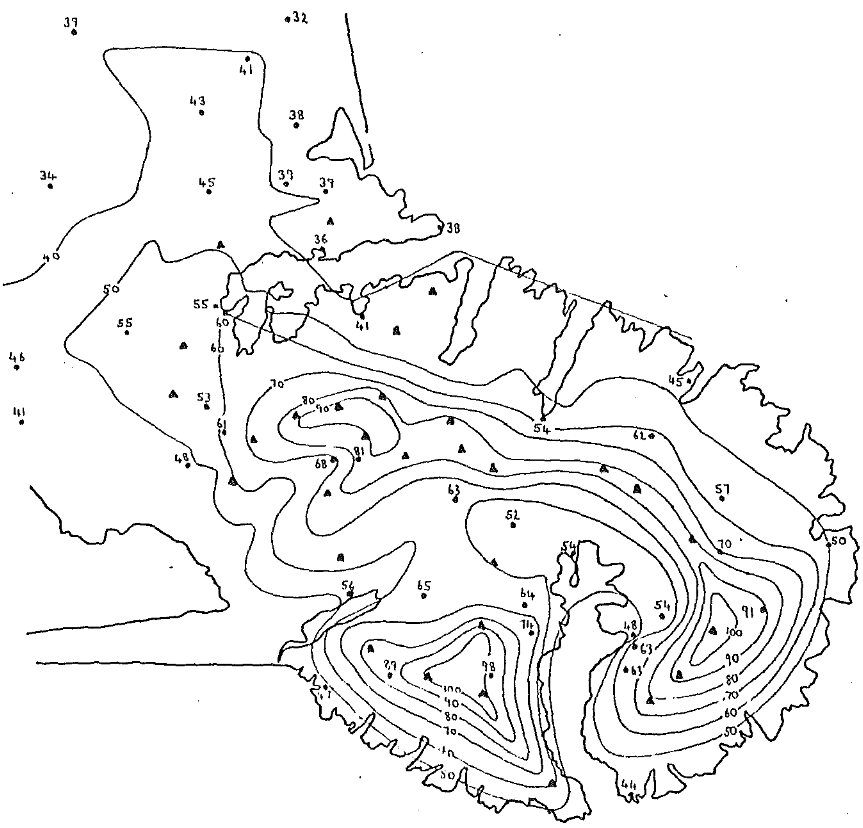
APPENDIX ONE

AVERAGE MONTHLY RAINFALL DISTRIBUTION OVER THE STUDY AREA

JANUARY

FEBRUARY



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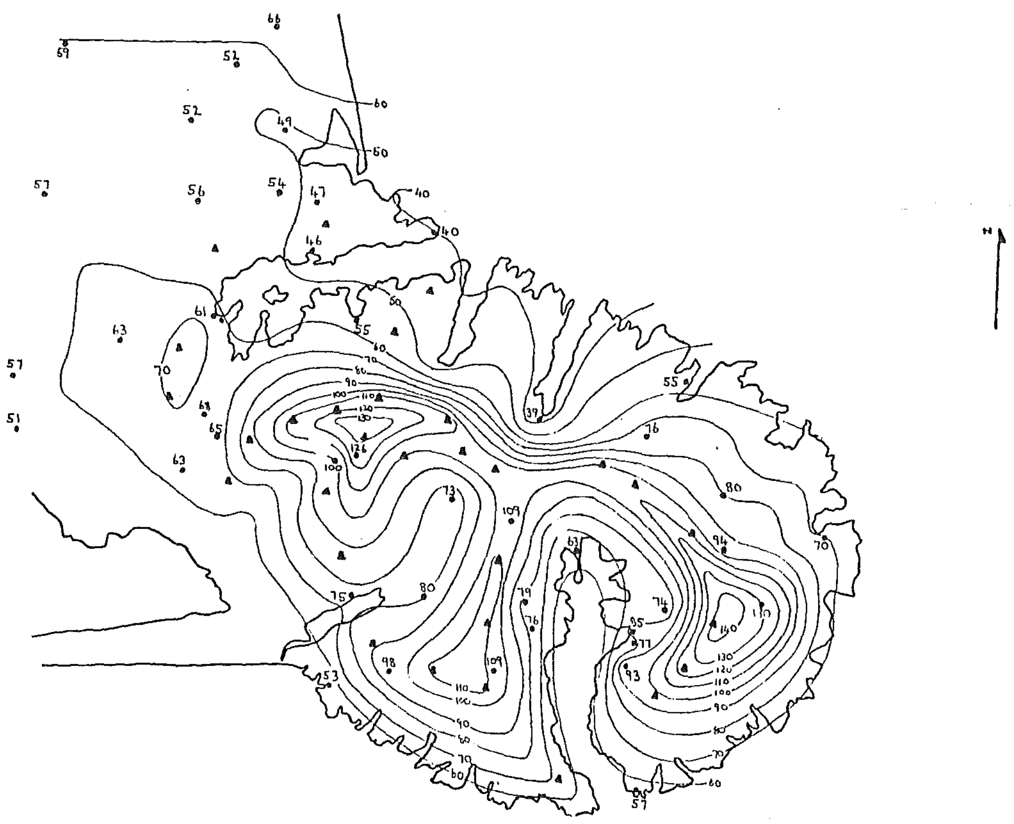

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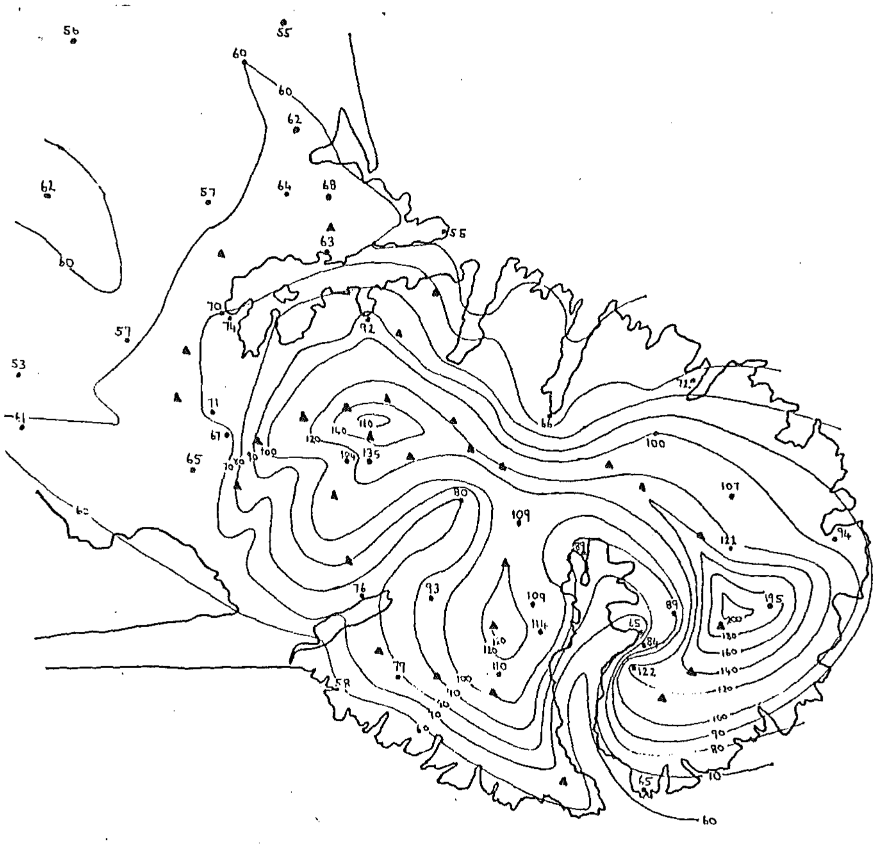

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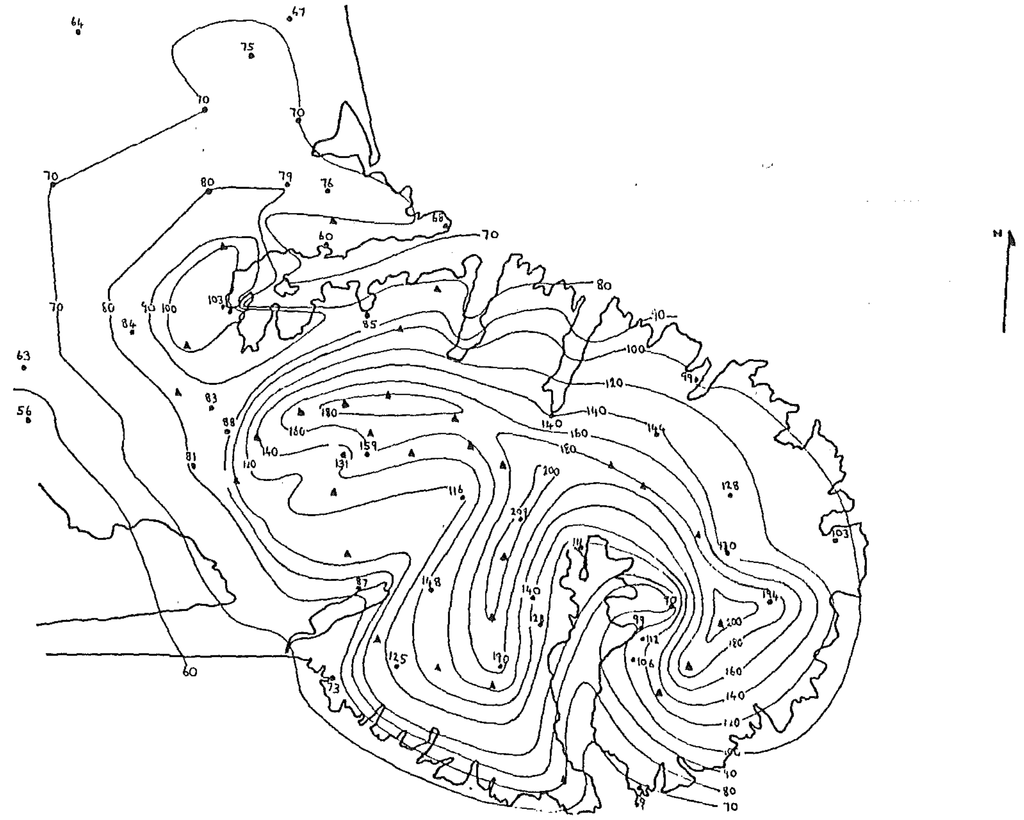

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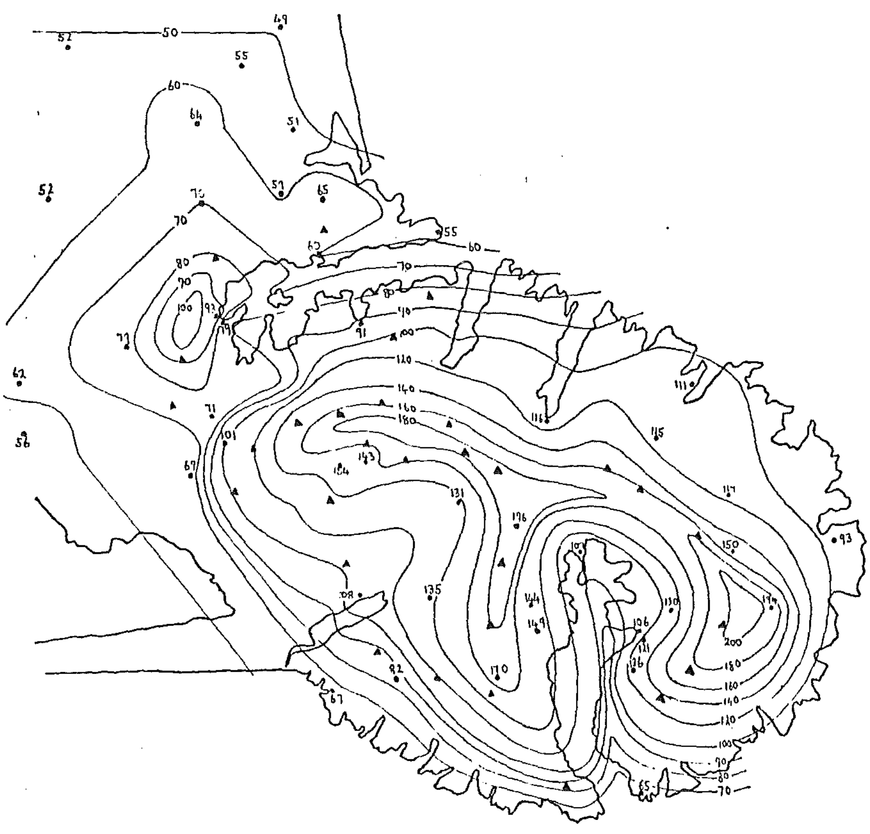

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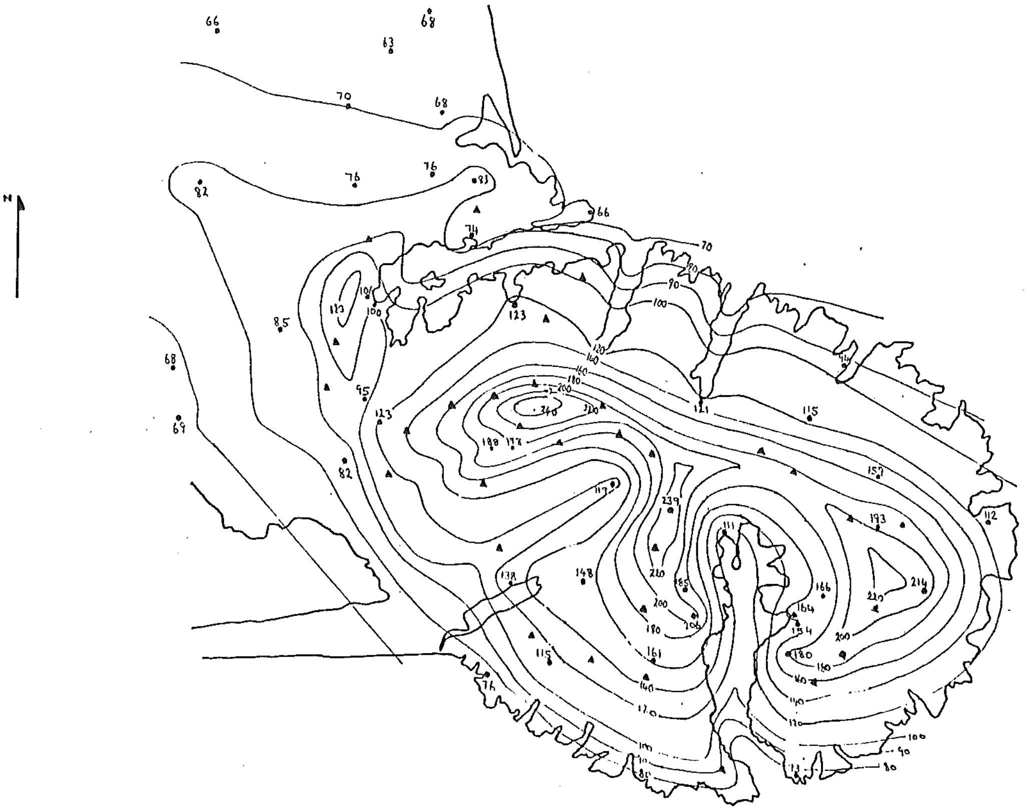
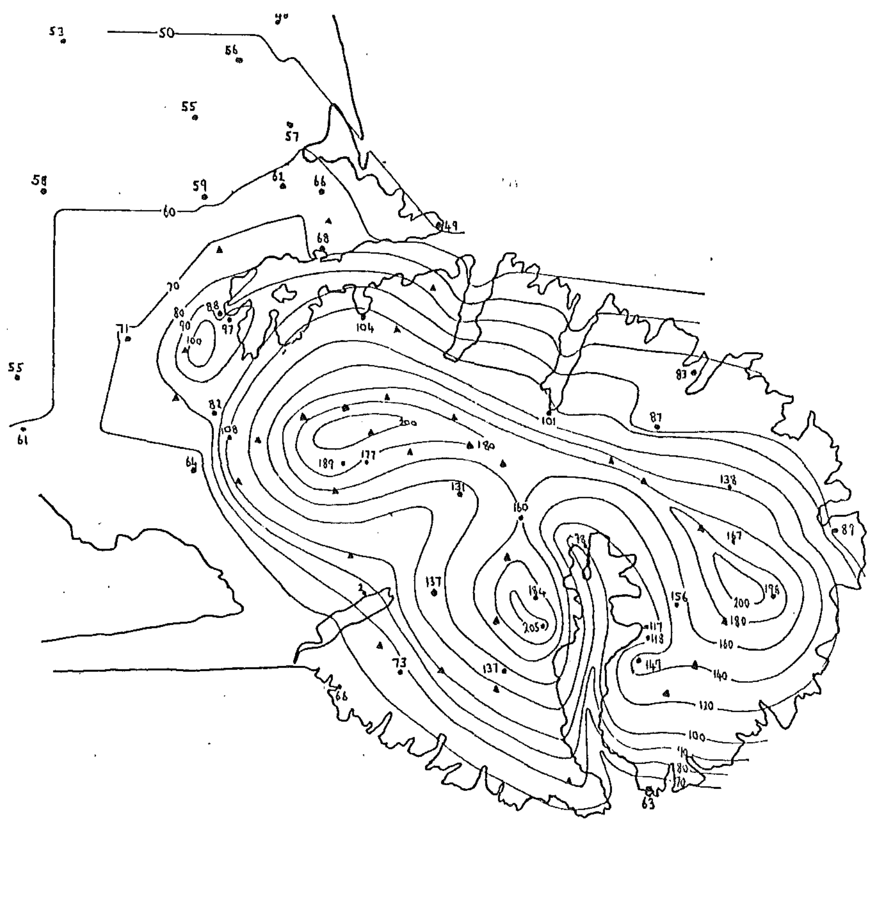


AUGUST

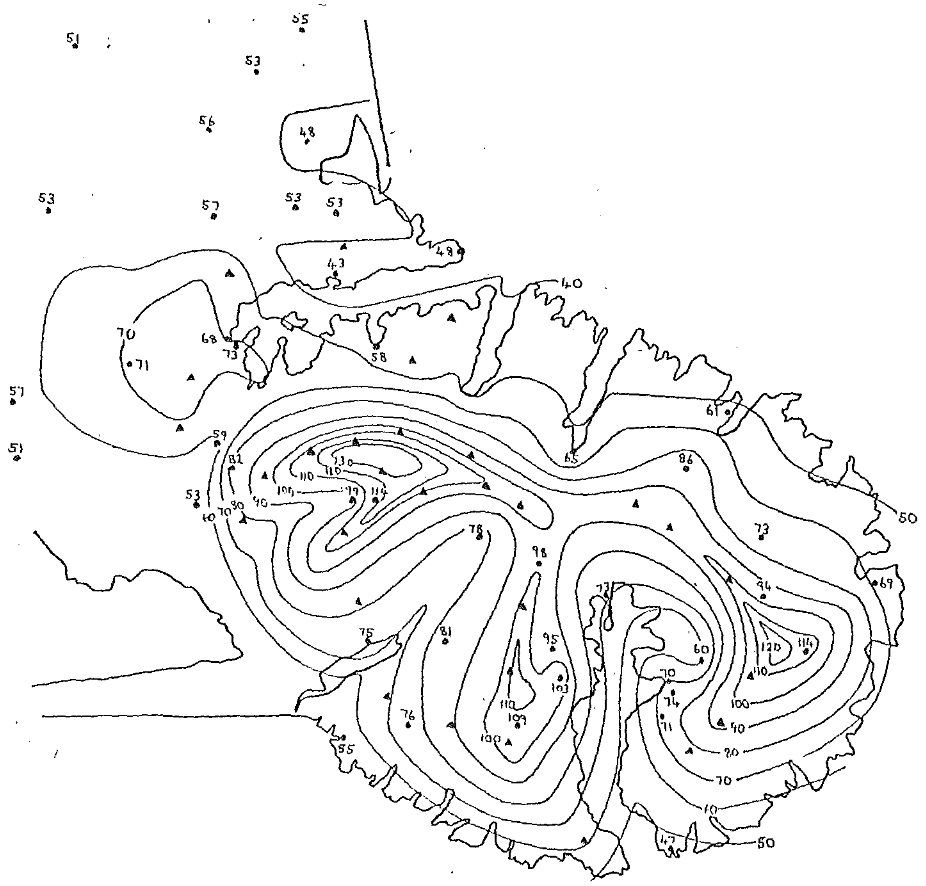


SEPTEMBER

OCTOBER

NOVEMBER

DECEMBER



APPENDIX TWO

MULTIPLE REGRESSION RESULTS FOR THE EIGHT REPRESENTATIVE RAINFALL STATIONS ON A SEASONAL BASIS USING THE THREE TIME SCALES

SUMMER

	Coefficients of circulation Indices					F	R	R^2
	CYCLONIC	WESTERLY	SOUTHERLY	EASTERLY	NORTHERLY	TEST (%)		
			RECORD PERIOD (1929-1985)					
Ch-Ch*	0.44^{c}				-0.34^{e}	1	0.56	0.31
Lincoln	0.42^{c}				-0.35^{e}	1	0.55	0.30
Akaroa						5	0.45	0.20
Okuti	0.40^{c}				-0.32^{f}	1	0.51	0.26
Allandale	0.30^{f}					2.5	0.48	0.23
Magnet	0.27^{f}						0.39	0.15
Akaloa	0.46^{c}				-0.29^{f}	1	0.56	0.31
Le Bons								
			10 YEAR MOVING TREND					
Ch-Ch	0.34^{d}		0.82^{a}		-0.37^{f}	1	0.90	0.81
Lincoln			1.00^{a}			1	0.90	0.81
Akaroa	-0.27^{e}	0.41^{a}	1.20^{a}			1	0.92	0.85
Okuti	0.33^{e}		0.95^{a}			1	0.88	0.77
Allandale			0.93^{a}			1	0.89	0.78
Magnet			0.78^{a}			1	0.88	0.78
Akaloa	0.57^{a}		0.64^{a}	-0.48^{c}	-0.82^{b}	1	0.88	0.78
Le Bons	0.85^{d}				-0.84^{f}	2.5	0.69	0.47
			30 YEAR MOVING TRENDS					
Ch-Ch		0.23^{f}	1.26^{a}	0.72^{a}		1	0.97	0.94
Lincoln			1.15^{a}	0.49^{e}		1	0.96	0.91
Akaroa		0.25^{e}	1.33^{a}	0.64^{a}		1	0.98	0.95
Okuti		0.28^{f}	1.23^{a}	0.97^{a}		1	0.95	0.91
Allandale		0.36^{d}	1.24^{a}	0.65^{b}		1	0.96	0.93
Magnet			1.16^{a}	0.75^{a}		1	0.96	0.93
Akaloa	0.32^{d}		1.15^{a}	0.88^{a}		1	0.95	0.90
Le Bons			0.52^{d}	0.45^{e}		1	1.00	1.00

Significant levels: a = 0.1%; b = 0.2%; c = 1%; d = 2%; e = 5%; f = 10 %
* Christchurch

AUTUMN

	Coefficients of circulation Indices					F	R	R^2
	CYCLONIC	WESTERLY	SOUTHERLY	EASTERLY	NORTHERLY	TEST (%)		
RECORD PERIOD (1929-1985)								
Ch-Ch							0.34	0.1
Lincoln							0.35	0.1
Akaroa							0.36	0.1
Okuti			0.31[e]				0.39	0.1
Allandale	0.30[e]					5	0.46	0.2
Magnet			0.30[f]	0.29[f]		5	0.47	0.2
Akaloa							0.35	0.1
Le Bons								
10 YEAR MOVING TRENDS								
Ch-Ch	0.41[e]				-0.81[f]	2.5	0.52	0.2
Lincoln	0.36[f]	-0.61[e]	0.63[f]		-1.26[c]	10	0.46	0.2
Akaroa		-0.50[e]	0.97[d]		-0.92[e]	1	0.63	0.4
Okuti		0.55[c]		0.55[a]		1	0.66	0.4
Allandale	0.29[f]		1.00[a]	-0.34[d]		1	0.72	0.5
Magnet	0.37[c]	-0.67[a]	0.91[a]		-1.15[a]	1	0.79	0.6
Akaloa			0.88[d]		-0.79[f]	5	0.50	0.2
Le Bons	-0.99[a]	0.64[e]			-1.01[c]	1	0.77	0.6
30 YEAR MOVING TRENDS								
Ch-Ch	0.53[b]	1.40[f]			1.56[e]	1	0.75	0.5
Lincoln	0.46[b]	1.41[e]			1.30[e]	1	0.83	0.6
Akaroa			0.78[f]			1	0.94	0.8
Okuti		2.20[c]				1	0.74	0.5
Allandale	0.27[b]					1	0.95	0.9
Magnet	0.28[a]		1.22[b]	0.35[a]		1	0.96	0.9
Akaloa					0.91[f]	1	0.88	0.7
Le Bons	4.46[f]			2.86[f]		5	1.00	0.9

<u>WINTER</u>

	Coefficients of circulation Indices					F	R	R^2
	CYCLONIC	WESTERLY	SOUTHERLY	EASTERLY	NORTHERLY	TEST (%)		
			RECORD PERIOD (1929-1985)					
Ch-Ch	0.50[c]			0.32[e]		1	0.63	0.39
Lincoln	0.41[c]			0.29[f]		10	0.55	0.31
Akaroa	0.35[d]		0.33[d]	0.34[d]		1	0.60	0.36
Okuti	0.40[c]		0.29[e]	0.37[d]		1	0.59	0.35
Allandale	0.34[e]		0.34[e]			1	0.52	0.28
Magnet	0.43[c]		0.32[d]	0.41[c]		1	0.52	0.28
Akaloa	0.41[c]		0.32[d]	0.29[e]		1	0.58	0.34
Le Bons								
			10 YEAR MOVING TRENDS					
Ch-Ch	0.58[c]	0.39[f]	0.69[a]	0.53[a]	-0.43	1	0.86	0.74
Lincoln	0.62[e]	0.60[e]	0.98[a]		-0.67	1	0.74	0.55
Akaroa	0.63[e]	0.58[e]	0.59[b]	0.32[f]	-0.46	1	0.70	0.48
Okuti	0.77[b]	0.63[c]	0.52[a]	0.37[c]	-0.62	1	0.81	0.65
Allandale		0.52[c]	1.01[a]	0.51[a]		1	0.87	0.75
Magnet	0.72[a]	0.53[d]	0.67[a]	0.45[a]	-0.46	1	0.85	0.73
Akaloa	0.38[f]	0.53[d]	0.77[a]	0.52[a]		1	0.83	0.69
Le Bons	0.84[a]	0.19[f]		0.43[b]	-0.40[a]	1	0.96	0.92
			30 YEAR MOVING TRENDS					
Ch-Ch	0.48[d]		1.08[b]		-0.72[f]	1	0.83	0.69
Lincoln			1.54[a]			1	0.75	0.57
Akaroa	0.71[c]		0.91[d]			1	0.75	0.56
Okuti	0.46[d]		0.79[c]			1	0.85	0.73
Allandale			1.52[a]	0.66[f]		1	0.84	0.71
Magnet	0.43[e]		1.08[c]	0.72[f]		1	0.8	0.64
Akaloa	0.55[c]		1.32[a]	0.63[f]	-0.82[e]	1	0.85	0.73
Le Bons		0.74[f]	1.04[f]	1.47[e]		5	0.99	0.99

SPRING

	Coefficient of circulation Indices					F	R	R^2
	CYCLONIC	WESTERLY	SOUTHERLY	EASTERLY	NORTHERLY	TEST (%)		
			RECORD PERIOD (1929-1985)					
Ch-Ch				0.26^{f}			0.36	0.13
Lincoln				0.30^{e}		10	0.40	0.16
Akaroa			0.27^{f}	0.31^{e}		2.5	0.50	0.25
Okuti			0.27^{f}	0.38^{d}		5	0.46	0.21
Allandale			0.35^{e}			5	0.44	0.19
Magnet			0.39^{d}			5	0.42	0.18
Akaloa			0.27^{f}	0.28^{f}		5	0.46	0.21
Le Bons								
			10 YEAR MOVING TRENDS					
Ch-Ch	0.28^{c}	-0.59^{c}	0.74^{a}	0.18^{e}		1	0.92	0.85
Lincoln	-0.31^{c}		0.71^{a}		0.73	1	0.90	0.81
Akaroa	-0.31^{c}	-0.48^{e}	0.80^{a}			1	0.93	0.86
Okuti	-0.37^{a}		0.82^{a}	0.24^{d}	0.55	1	0.92	0.84
Allandale		0.40^{f}	0.69^{a}		0.69	1	0.90	0.80
Magnet		-1.08^{a}	0.52^{a}	0.31^{c}	-0.58	1	0.87	0.76
Akaloa		-0.50^{d}	0.75^{a}			1	0.93	0.86
Le Bons		-0.92^{e}	0.78^{a}			1	0.96	0.93
			30 YEAR MOVING TRENDS					
Ch-Ch	-0.30^{f}		0.75^{a}			1	0.91	0.83
Lincoln			0.76^{a}		0.57^{e}	1	0.98	0.96
Akaroa	-0.17^{e}		0.74^{a}			1	0.98	0.96
Okuti	-0.22^{e}		0.71^{a}			1	0.97	0.95
Allandale			0.60^{a}		0.77^{e}	1	0.97	0.94
Magnet	-0.46^{a}		0.58^{a}			1	0.95	0.91
Akaloa	-0.13^{f}		0.73^{a}			1	0.98	0.96

APPENDIX THREE

MULTIPLE REGRESSION RESULTS FOR THREE TEMPERATURE STATIONS (CHRISTCHURCH, LINCOLN, AND ONAWE) ON A SEASONAL BASIS USING THE THREE TIME SCALES

SUMMER

	Coefficients of circulation Indices					F	R	R^2
	CYCLONIC	WESTERLY	SOUTHERLY	EASTERLY	NORTHERLY	TEST (%)		
RECORD PERIOD (1929-1985)								
CH-CH*								
Maximum			-0.67[a]	-0.45[d]		1	0.68	0.46
Minimum			-0.53[b]		0.25[f]	1	0.74	0.55
Mean			-0.69[a]	-0.31[f]		1	0.75	0.56
LINCOLN								
Maximum			-0.47[d]	-0.43[e]	0.34[e]	1	0.63	0.39
Minimum			-0.58[a]			1	0.72	0.51
Mean			-0.58[b]		0.30[f]	1	0.69	0.47
ONAWE								
Maximum			-0.43[e]	-0.41[e]	0.36[f]	1	0.63	0.39
Minimum	-0.30[f]		-0.31[f]		0.30[e]	1	0.59	0.35
Mean	-0.26[f]		-0.46[c]		0.41[d]	1	0.71	0.50
10 YEAR MOVING TRENDS								
CH-CH								
Maximum		-0.22[e]	-1.30[a]	-0.54[a]		1	0.97	0.93
Minimum	-0.42[c]		-0.63[c]			1	0.94	0.89
Mean		-0.22[e]	-1.20[a]	-0.37[c]		1	0.97	0.93
LINCOLN								
Maximum	-0.30[f]	-0.28[f]	-1.40[a]	-0.74[a]		1	0.91	0.82
Minimum			-0.80[a]			1	0.95	0.91
Mean			-1.11[a]	-0.28[f]		1	0.95	0.90
ONAWE								
Maximum	-0.62[c]		-0.86[c]	-0.79[b]		1	0.88	0.77
Minimum	-0.48[a]		-0.74[a]			1	0.95	0.90
Mean	-0.50[c]		-0.91[a]	-0.41[e]		1	0.95	0.90
30 YEAR MOVING TRENDS								
CH-CH								
Maximum		-0.30[e]	-1.31[a]	-0.98[a]		1	0.98	0.96
Minimum		-0.34[e]	-1.27[a]	-0.97[a]		1	0.98	0.96
Mean		-0.29[f]	-1.32[a]	-0.96[a]		1	0.98	0.96
LINCOLN								
Maximum		-0.29[f]	-1.26[a]	-0.99[a]		1	0.98	0.95
Minimum		-0.30[e]	-1.34[a]	-0.93[a]		1	0.98	0.97
Mean		-0.33[e]	-1.32[a]	-0.99[a]		1	0.98	0.96
ONAWE								
Maximum		-0.29[f]	-1.23[a]	-1.02[a]		1	0.98	0.96
Minimum		-0.42[d]	-1.33[a]	-1.04[a]		1	0.98	0.96
Mean		-0.27[f]	-1.26[a]	-0.97[a]		1	0.98	0.95

SIGNIFICANT LEVELS: a = 0.1%; b = 0.2%; c = 1%; d = 2%; e = 5%; f = 10%

* Christchurch

AUTUMN

	Coefficients of circulation Indices					F	R	R^2
	CYCLONIC	WESTERLY	SOUTHERLY	EASTERLY	NORTHERLY	TEST (%)		
			RECORD PERIOD (1929-1985)					
CH-CH								
Maximum		0.42^d	-0.41^c			1	0.62	0.39
Minimum			-0.40^c	0.47^a		1	0.67	0.45
Mean		0.32^e	-0.48^c	0.29^e		1	0.64	0.42
LINCOLN								
Maximum		0.48^f				5	0.49	0.24
Minimum			-0.36^d	0.53^a		1	0.66	0.43
Mean		0.42^d	-0.38^d	0.40^c		1	0.64	0.41
ONAWE								
Maximum			0.35^e	-0.42^c		1	0.58	0.34
Minimum			-0.29^f	0.42^c		1	0.56	0.32
Mean		0.30^f	-0.45^c	0.24^f		1	0.60	0.36
			10 YEAR MOVING TRENDS					
CH-CH								
Maximum			-1.01^a		0.92^f	1	0.91	0.83
Minimum		0.58^f	-1.40^a		1.01^e	1	0.80	0.64
Mean		0.44^f	-1.11^a		0.64^f	1	0.88	0.77
LINCOLN								
Maximum			-1.17^a			1	0.74	0.54
Minimum		0.92^a	-0.97^a		0.87^d	1	0.90	0.80
Mean		0.76^c	-1.10^a		0.99^e	1	0.82	0.67
ONAWE								
Maximum			-0.84^a			1	0.87	0.75
Minimum	0.41^f		-1.25^a			1	0.66	0.43
Mean		0.70^e	-1.10^a		0.93^f	1	0.77	0.59
			30 YEAR MOVING TRENDS					
CH-CH								
Maximum	0.18^e		-0.84^a	-0.09^f		1	0.99	0.98
Minimum		-0.99^f	-1.08^e		-0.92^e	1	0.95	0.90
Mean	0.22^e		-0.65^e			1	0.99	0.97
LINCOLN								
Maximum	0.19^f					1	0.98	0.97
Minimum	0.33^e					1	0.97	0.94
Mean			-0.66^e			1	0.98	0.96
ONAWE								
Maximum			-0.93^d			1	0.97	0.95
Minimum						1	0.91	0.83
Mean	0.24^f		-1.05^d			1	0.97	0.94

WINTER

	Coefficients of circulation Indices CYCLONIC	WESTERLY	SOUTHERLY	EASTERLY	NORTHERLY	F TEST (%)	R	R^2
RECORD PERIOD (1929-1985)								
CH-CH								
Maximum		0.34^{e}	-0.50^{b}			1	0.63	0.39
Minimum				0.30^{f}		2.5	0.52	0.27
Mean		0.34^{e}	-0.45^{c}			1	0.56	0.31
LINCOLN								
Maximum		0.30^{f}	-0.34^{d}	-0.27^{f}		1	0.58	0.34
Minimum		0.43^{d}		0.44^{c}	0.33^{f}	1	0.55	0.30
Mean		0.44^{d}	-0.29^{f}			2.5	0.53	0.28
ONAWE								
Maximum		0.54^{a}	-0.40^{b}			1	0.72	0.51
Minimum	0.32^{f}		-0.36^{e}			2.5	0.50	0.25
Mean		0.38^{d}	-0.45^{c}			1	0.60	0.36
10 YEAR MOVING TRENDS								
CH-CH								
Maximum	0.60^{c}		-0.65^{a}	-0.25^{f}	-0.68^{a}	1	0.91	0.82
Minimum	0.80^{c}	0.69^{c}		0.31^{f}		1	0.86	0.75
Mean	0.71^{b}		-0.59^{a}		-0.62^{a}	1	0.91	0.83
LINCOLN								
Maximum	0.59^{d}		-0.85^{a}		-0.62^{a}	1	0.88	0.77
Minimum	0.43^{d}	0.74^{a}		0.50^{a}		1	0.95	0.90
Mean	0.64^{a}	0.54^{b}	-0.33^{d}	0.26^{e}	-0.35^{b}	1	0.94	0.88
ONAWE								
Maximum	0.25^{f}	0.33^{d}	-0.65^{a}		-0.28^{b}	1	0.96	0.93
Minimum	1.26^{a}				-0.44^{f}	1	0.73	0.54
Mean	0.83^{a}	0.80^{a}	-0.50^{b}	-0.40^{a}	-0.41^{b}	1	0.91	0.83
30 YEAR MOVING TRENDS								
CH-CH								
Maximum	0.15^{e}	0.64^{a}	-0.71^{a}			1	0.98	0.97
Minimum			0.42^{f}	0.94^{e}		1	0.93	0.87
Mean	-0.14^{f}	0.36^{e}	-0.49^{c}	0.42^{f}	0.33^{f}	1	0.98	0.96
LINCOLN								
Maximum		0.51^{e}	-0.81^{a}	-0.74^{d}	-0.43^{f}	1	0.96	0.93
Minimum		0.60^{a}		0.65^{a}		1	0.99	0.98
Mean		0.77^{a}		0.46^{d}		1	0.99	0.97
ONAWE								
Maximum		0.44^{f}	-0.73^{f}			1	0.96	0.92
Minimum				1.16^{f}	1.20^{f}	5	0.76	0.58
Mean						1	0.88	0.77

SPRING

	Coefficients of circulation Indices					F	R	R^2
	CYCLONIC	WESTERLY	SOUTHERLY	EASTERLY	NORTHERLY	TEST (%)		
RECORD PERIOD (1929-1985)								
CH-CH								
Maximum			-0.49[a]	-0.64[a]		1	0.68	0.47
Minimum							0.38	0.15
Mean			-0.52[a]	-0.55[a]		1	0.63	0.40
LINCOLN								
Maximum			-0.40[c]	-0.69[a]		1	0.71	0.50
Minimum			-0.50[c]			10	0.47	0.22
Mean			-0.46[c]	-0.54[a]		1	0.60	0.36
CNAWE								
Maximum	-0.24[f]		-0.35[c]	-0.68[a]	0.37[d]	1	0.73	0.54
Minimum							0.32	0.10
Mean			-0.42[c]	-0.60[a]		1	0.64	0.41
10 YEAR MOVING TRENDS								
CH-CH								
Maximum	0.54[a]	-0.57[c]	-1.07[a]	-0.25[a]	-0.72[c]	1	0.97	0.94
Minimum	0.49[e]	-1.87[a]			-2.24[a]	1	0.78	0.60
Mean	0.53[a]	-0.91[a]	-0.93[a]	-0.17[e]	-1.14[a]	1	0.96	0.91
LINCON								
Maximum	0.43[b]	-0.52[f]	-0.98[a]	-0.47[a]		1	0.95	0.89
Minimum	0.71[a]	-0.90[b]	-0.39[a]		-1.71[a]	1	0.94	0.88
Mean	0.24[f]	-0.57[e]	-0.65[a]		-1.02[b]	1	0.94	0.89
CNAWE								
Maximum	-0.37[a]		-0.75[a]	-0.28[a]	0.76[b]	1	0.97	0.94
Minimum	1.02[a]	-1.17[c]	-0.78[a]		-1.60[b]	1	0.87	0.75
Mean	-0.49[b]	0.69[d]	-0.77[a]		0.73[e]	1	0.94	0.87
30 YEAR MOVING TRENDS								
CH-CH								
Maximum			-1.34[a]	-0.76[c]		1	0.97	0.94
Minimum	-0.73[f]		-0.67[e]			1	0.94	0.88
Mean			-0.73[e]			1	0.93	0.87
LINCOLN								
Maximum			1.46[c]			1	0.87	0.77
Minimum						1	0.95	0.91
Mean					-1.00[e]	1	0.97	0.94
CNAWE								
Maximum			-1.10[f]	-1.24[f]		10	0.72	0.51
Minimum			-1.39[a]	-0.66[c]		1	0.98	0.96
Mean		-0.96[f]	-0.93[d]	-0.56[f]	-1.65[e]	1	0.93	0.87